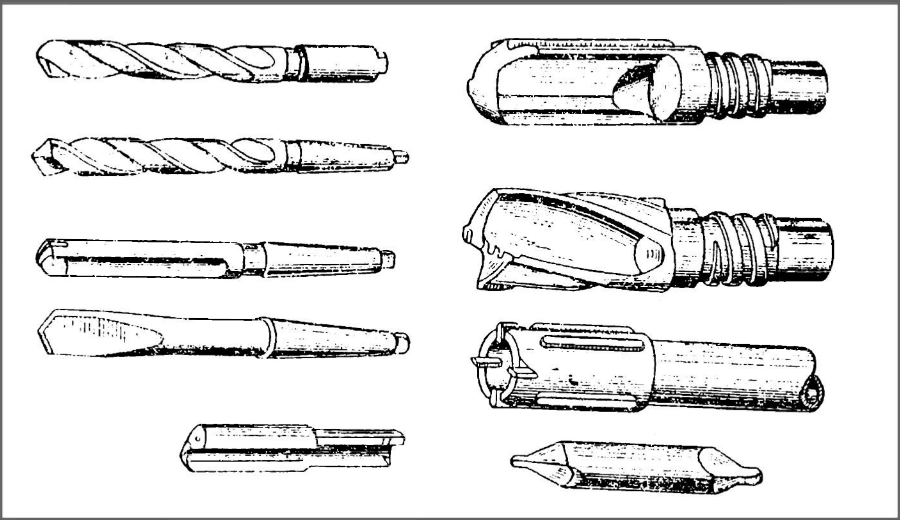
I. VINNIKOV, M. FRENKEL

DRILLING PRACTICE



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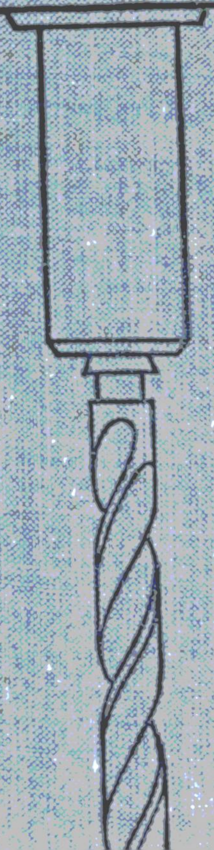

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I. VINNIKOV, M. FRENKEL

DRILLING PRACTICE

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RUSSIAN ALPHABET WITH TRANSLITERATION

Аа	a	Рр	r
Бб	b	Сс	s
Вв	v	Тт	t
Гг	g	Уу	u
Дд	d	Фф	f
Ее	ye	Хх	kh
Жж	zh	Цц	ts
Зз	z	Чч	ch
Ии	i	Шш	sh
Кк	k	Щщ	shch
Лл	l	Ыы	y
Мм	m	Ээ	e
Нн	n	Юю	yu
Оо	o	Яя	ya
Пп	p		

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INTRODUCTION

Machine-building works produce various equipment, machine tools, mechanisms and apparatus whose components contain a large number of round holes.

There are various ways of making these holes, but the most common is by drilling.

In the Soviet Union, drilling, together with other metal-working processes, is constantly being studied and improved by scientists, engineers and progressive workers. Soviet factories are today equipped with highly efficient drilling machines, which automatically drill scores of holes simultaneously and at high speeds.

In a modern machine-building factory drilling machines account for from 12 to 15 per cent of the total number of machine tools. General-purpose drills are the most common type of drilling machines in use.

The universal nature of drilling machines enables them to perform many various operations besides drilling: core drilling, countersinking, boring, reaming and expanding holes, spotfacing and chamfering. In addition, these machines can cut threads, drill polygonal holes, trepan large-diameter holes in sheet material, machine profiled recesses in holes, form rivet heads, and so on.

Not all of these operations are typical of drilling machines, but drilling machine operators must become acquainted with them. Therefore, in addition to a basic treatment of the drilling of holes, this book describes other operations which can be performed on these machine tools,

Chapter I

GENERAL

1. Production Management

The type of production of an article depends on the demand for that article.

There are three basic types of production: piece, lot and mass production.

By *piece* production is understood the production of articles in small quantities; such production rarely entails the repetition of their manufacture.

Piece production is characterized by a low degree of mechanization in the machining of parts; by manual assembly; the use of general-purpose equipment; machine tools grouped according to purpose (process layout); the employment of fitting operations during assembly; a low degree of division of labour (individual or brigade method of production) and the use of special jigs or fixtures only in cases of extreme necessity.

Piece production is prevalent in factories producing pilot models and in heavy engineering works.

By *lot* production is understood the manufacture of parts in small, medium or large lots, the repetition of each lot being planned in advance.

Large lot production is characterized by the wide mechanization of machining operations and the layout of machine tools according to the sequence of processing operations (product layout), and by the employment of special-purpose machines and general-purpose machines that can be changed over for each new job. In addition, assembly operations are mechanized and usually performed with interchangeable parts, jigs and fixtures are widely employed, and the whole process is broken up into separate operations, only a limited number of which (3-4) being performed at each workplace.

While in-line production of parts is entirely absent in piece production, it is employed in lot production when the lots are sufficiently large.

The majority of machine-building works manufacturing machine tools, compressors, pumps and printing machines operate on the lot production principle.

By *mass* production is understood the continuous manufacture of products in large quantities over long periods of time.

Mass production presupposes the complete mechanization of the machining operations and the predominant use of specialized and highly specialized equipment (such as unit-built machine tools) arranged according to the sequence of operations to be performed. Complicated fixtures and special tools are used, assembly operations employing completely interchangeable parts are mechanized to a high degree, and the specialization of the operators' workplaces allows only one continuously repeated operation to be performed at each such workplace. All these factors allow the use of different forms of in-line production methods, including continuous flow production.

Mass production is employed, for example, by works manufacturing electrical appliances, sewing machines, tractors, automobiles, ball bearings, etc.

By *continuous flow* production is understood a production process in which workplaces are arranged in the sequence of operations to be performed. The number and capacity of each station is so calculated that the machined or assembled parts are transferred from operation to operation without any delay.

Continuous flow production is, therefore, the most perfect form of the organization of production. Depending on the degree of mechanization, continuous flow production is subdivided into manual flow, distributing-conveyor, processing-conveyor and transfer-machine production.

Manual flow production is the simplest form of continuous flow production. Operators transfer parts from one workplace to the next manually or by means of simple transportation methods (skids, rollers, trucks, etc.).

Distributing-conveyor lines consist of a series of workplaces served by a common conveyor, which transports the parts from one operation to the next. The parts are

removed from this conveyor at each workplace and replaced after performing the operation.

Processing conveyors are production lines in which operations are performed without removing the parts from the conveyor. This saves labour and time in shifting the parts. The design of processing conveyors is considerably more complicated than that of distributing conveyors.

Automatic transfer machines are the highest form of continuous flow production. They consist of a number of automatically controlled and coordinated machine tools or units, and handling and inspecting facilities used for machining and assembling parts.

The machine shops of machine-building works use automatic transfer machines comprising specially designed or adapted standard machine tools.

An indispensable condition for the organization of continuous flow production (especially with the use of conveyors or transfer machines) is *rhythmic operation*, i.e., execution of work *at a constant rate*. Continuous in-line production requires that each operation of a given process be performed in interval of time equal in duration to that in which machined parts or assembled articles enter or leave the line. This interval of time is known as the *cycle time.*

This condition is best fulfilled by the processing conveyor and the transfer machine, where the cycle time is determined by the handling mechanism which *automatically* transfers the work from one workplace to the next at predetermined time intervals.

One or several types of parts may be machined (or assembled) on one production line. Thus, we distinguish the *single line* (one type of parts) and the *group production line* (several types of parts).

2. Basic Manufacturing Processes

The production process of a modern enterprise consists of the *direct processing* of materials, resulting in changes in the shape, dimensions or properties of the materials, and of *auxiliary processes.* The latter include handling and storage of materials, preparation for production, supply of power and tools to workplaces, production management, inspection and testing, etc.

The auxiliary processes do not directly affect the shape or properties of the material being processed; they are, however, essential for the systematic and rational execution of the production processes.

The production process, therefore, is a combination of all the processes entailing the conversion of raw materials into a finished product at a given enterprise.

Direct processing of materials at machine-building works is subdivided into the following basic stages:

manufacturing blanks;

converting blanks into parts;

heat treatment and casehardening of parts;

deposition of protective coatings;

assembly of units and products.

In order to execute these stages of the production process, described briefly below, engineering works usually consist of the following shops:

blank production (sheet cutting, foundry, forge, press-working and others);

machine;

heat treating;

metal coating and paint;

assembly;

auxiliary (tool rooms, machine maintenance, building maintenance, etc.).

Metal stock, such as rods, wires, strip, sheet, rolled stock, etc., is as a rule delivered to engineering plants from metallurgical works.

Engineering works often specialize in the production of certain blanks or parts, not only for their own use but for other works on a cooperative basis.

Production specialization and cooperation considerably increase the output capacity of an enterprise and lower production costs.

3. Production of Blanks

Before a part is manufactured, the material from which it is to be made is converted into so-called *blanks*. These are made of a shape and size approaching, as closely as possible, those of the finished part. This ensures economy in material and electric power, raises the output, etc.

Depending on the material, the purpose of the part, the required accuracy, etc., blanks are produced by casting, flat- or closed-die forging, heading, rolling, drawing and other methods.

Casting consists in pouring molten metal into special moulds. After the metal has cooled, the mould is separated (or broken up) to leave a casting (blank) of predetermined shape and size.

Blanks are cast of iron, steel, nonferrous metals and their alloys by various methods: by casting in sand, permanent and shell moulds, by die-casting, centrifugal casting and investment casting methods.

Sand casting is widely used, as the cost of sand moulds is much lower than of those used in other casting methods. Sand moulds are made of so-called moulding sand, consisting of sand, clay and special fillers.

The accuracy and finish of a sand casting depend on the raw materials, the quality of moulds and equipment, and on the casting technique employed.

Metal can be poured into a sand mould only once, i.e., only one casting is obtained from each mould. This casting method, therefore, has a low output and, moreover, is less accurate then other methods of casting blanks.

Permanent mould casting is more efficient than sand casting, as several castings may be made from one mould. Higher surface finish and greater accuracy of the blank dimensions are ensured.

Shell mould casting is a comparatively new method of producing ferrous and nonferrous metal blanks and parts. Moulds are made with bonding agents consisting of thermosetting resins. The moulding mixture is applied to the surface of a heated metal pattern, the thermosetting resin melts and a hard skin 5 to 7 mm thick is formed on the pattern. Then the mould, with its slightly hardened shell, is baked in an oven where the final setting takes place. The mould is then removed from the pattern by pushers and is passed on for filling with molten metal.

The simplicity of making shell moulds, the considerable reduction in machining allowances and the high accuracy of the dimensions of intricately shaped castings (± 0.2 mm per 100 mm length), are the main advantages of this method, which is finding an ever-increasing application.

Die-casting is particularly widely used in the production of electrical and radio equipment and similar articles. This method consists in forcing liquid metal into a metal mould under pressure, higher than atmospheric, and thereby making sure that all the recesses of the mould are filled. Pressure casting is used for the production of complex nonferrous alloy castings with projections, bosses and holes.

Investment casting is based on the use of investment patterns *, which are formed in metal press moulds by filling them with a liquid moulding mixture or by injecting a pasty mixture with a press. Accurate and clean castings are obtained by this method. The particular advantage of investment casting method lies in that it produces not only blanks, but finished parts of intricate shape, requiring no machining.

Centrifugal casting involves pouring molten metal into a mould rotating rapidly around its vertical or horizontal axis. This method is most effective for obtaining circular blanks, pipes, gears, etc.

Forging includes several processes of shaping heated metal by blows or pressure, by means of hammers, presses and forging machines. If the heated metal is processed without special dies, the process is called *smith forging*; if in dies—*drop* or *closed-die forging*. Blanks are produced considerably faster by closed-die than by smith forging. Moreover, they are more accurate in shape and size, and require smaller allowances for subsequent machining.

Pressworking is a method of producing blanks and parts from sheet, bar and strip material by blanking, bending, drawing or flanging in dies mounted on presses.

Pressworking is very efficient and is widely used in various types of production.

Heading, like forging and pressworking, is a method of producing blanks by the plastic deformation of the material. For example, heads of blanks for bolts, screws, rivets, etc., are produced by heading wire or bar stock in special automatic machines **, which makes the method highly productive.

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* Pattern material is usually a paraffin-stearine mixture.

** Bolts, screws, etc., and their blanks are also produced on lathes and automatic machine tools by turning, but this method is less productive than heading.

If the diameter of the blank does not exceed 24 mm, the heads are upset without any preliminary heating of the material; for larger diameters the material must be heated before upsetting.

Rolling. Metal, either heated or cold, is passed between the rolls of a rolling mill. Depending on the shape of the rolls (smooth or grooved), stock of different sections can be produced. Rails, all kinds of beams (tees, Z-shapes, etc.), sheets, strip, pipes, rods, wires, etc., are produced by this method.

Drawing. By this method the metal is drawn through an orifice in a draw plate (die). Since the size of the opening in a draw plate is less than that of the worked material, the cross-section of the latter is reduced owing to the flow of the metal. By drawing, we can alter the shape of the cross-section of the drawn material: for example, a suitable opening in the die enables hexagonal or square cross-sections to be obtained from a round bar. This method is used for producing rods, wires and pipes of small diameters, etc.

4. Machining and Assembling Methods

Machining. To produce a part from a blank the latter must be machined, the excess material—*allowance*—being removed from its surface. The shape, dimensions and surface finish of a part must satisfy the requirements of the drawing to which it is made. This is achieved by machining the surfaces of the blank with various cutting tools.

When working by hand (bench work), tools such as files, chisels, scrapers, etc., are used; *when working on metal-cutting machine tools* (machining)—various single-point tools, milling cutters, drills, counterbores, broaches, grinding wheels, etc., are used.

Depending on the shape of the machined surface, the properties of the material, the required accuracy and other factors, machining is performed on metal-cutting machine tools by turning, milling, planing, drilling, grinding, broaching, etc.

External round, conical and shaped surfaces are turned, milled, broached and ground.

Round holes are obtained by drilling, enlarging, boring, reaming, broaching and grinding, and shaped holes

and grooves of various shapes by slotting, milling, grinding and broaching.

Flat surfaces are produced by planing, milling, grinding and broaching.

External threads are cut on lathes, thread-milling, bolt-threading, thread-rolling and thread-grinding machines. *Internal threads* (in holes) are cut on lathes, drilling, tapping and thread-milling machines.

Gear blanks are machined on special gear shapers, gear generators, gear-hobbing, gear-grinding and other machine tools, operating by the single-indexing or generating principle. In the first case, the shape of the cutter corresponds to that of the tooth space; the spaces are cut consecutively (one after another) over the whole surface of the blank. In the second case, both cutter and blank are given a motion corresponding to the meshing of a gear with a gear rack or the meshing of two gears.

Gears are finish-machined by grinding, shaving and lapping.

In recent years, new processing methods have been finding widespread application in industry. These include *ultrasonic, electrical discharge* (spark erosion) machining, *electrolytic* machining (for instance, electrolytic milling) and *various methods of plastic deformation of metal* (for instance, gear and spline rolling).

Heat treating and **casehardening** are important methods in the processing of materials (blanks or parts). The internal structure and mechanical properties of metals and alloys can be altered by these methods. All the important parts of machines, tools, etc., are heat treated or casehardened. *

Protective coatings. In order to protect metal products from destruction (corrosion) under the action of the surrounding medium (air, water, oil, various chemicals) different kinds of protective coating are applied: *metal plating* (zinc, lead, cadmium, tin, copper, chromium, nickel, silver, gold), *chemical* (bluing, phosphate coating, oxide coating) and *nonmetal* (varnishes, paints) **.

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* Heat treating and casehardening processes, corrosion of metals and their protection are described in Ch. II "Basic Data on Materials", Secs. 6 and 7.

** See Ch. II "Basic Data on Materials", Secs. 6 and 7.

Welding is one of the most economical methods for the permanent joining of parts by local heating and fusion of metal. Welding is also used in manufacturing blanks for producing various parts, units and other machine elements.

Depending on the heat source used for heating the parts being welded, we distinguish the following welding methods: manual electric-arc welding, automatic submerged-arc welding, argon-arc, gas welding, resistance welding, spot welding, etc.

Assembly is the process by which a complete product is obtained from its separate parts. Usually, the parts are not assembled into the article in one operation. They are first assembled into simple, then more complicated units, then groups and, finally, into the finished product. This assembly sequence considerably simplifies the process and permits mechanization, the use of fixtures, conveyors, and so on.

Chapter II

BASIC INFORMATION ON MATERIALS

1. Metals and Alloys

Metals are substances, which are distinguished by their specific lustre, malleability and electrical conductivity. They are used in engineering for manufacturing machines, machine tools, mechanisms and structures.

Metals are able to combine with each other and with certain metalloids (carbon, silicon and others), to form chemical compounds or mechanical mixtures—*alloys*. These combinations have more valuable properties than pure metals and, therefore, are widely used.

2. Properties of Metals

The properties of metals are subdivided into physical, chemical, mechanical and processing.

Physical properties of metals:

density—the quantity of a metal contained in a unit volume;

fusibility—the ability of a metal to change from the solid to the liquid state at a definite temperature;

thermal conductivity—the ability of a metal to conduct heat at a certain rate, when heated;

electrical conductivity—the ability of a metal to conduct electric current;

thermal expansion—the ability of a metal to increase its volume during heating.

Chemical properties of metals:

oxidizability—the ability of a metal to be affected by an oxidizing medium;

corrosion resistance—the ability of a metal to resist corrosion.

Mechanical properties of metals:

hardness—the resistance of a metal to penetration by a harder body;

strength—the ability of a metal to resist the action of external forces;

toughness—the ability of a metal to resist rapidly increasing impact loads;

elasticity—the ability of a metal to return to its original shape and dimensions after the removal of the load;

plasticity—the ability of a metal to alter its shape, without destruction, under the action of a load and to retain its new shape after removal of the load.

Processing properties of metals:

malleability—the ability of a metal to alter its shape in heated or cold condition under the action of external forces;

weldability—the ability of two pieces of metal to be joined firmly during heating to form a single piece;

fluidity—the ability of molten metal to flow freely and fill a mould thoroughly;

hardenability—the ability of metal to harden to varying depths;

machinability—the ease with which a metal may be worked with a cutting tool at a definite speed and cutting force.

3. Ferrous Metals

Ferrous metals include cast irons and steels, which are alloys of iron and carbon and which also contain silicon, phosphorus, manganese, sulphur and other elements.

Cast iron is an alloy of iron and carbon, containing over 2 per cent carbon. It also contains silicon, manganese, phosphorus and sulphur.

Pig iron is smelted from iron ores in blast furnaces. The raw materials used in its production are, besides the ore, fuel and fluxes.

Iron ore is a mineral ore containing compounds of iron and admixtures of other elements. Cast iron is obtained from the following iron ores: red and brown hematites and magnetite.

Coke is mainly used as *fuel.*

Fluxes are used for separating the earthy impurities (oxides of silicon, calcium, manganese, and other com-

pounds) from the iron in the ore; these impurities promote the formation of slags and are thus detrimental to the smelting process.

Carbon is contained in cast iron as a mechanical admixture (free graphite) and in chemical combination with iron in the form of iron carbide (also known as cementite). Cast irons containing carbon in the form of free graphite reveal a grey, coarse-grained structure in fracture. They are easily machined, possess good casting properties, a relatively low melting point (1,100-1,200° C), low shrinkage (1 per cent), and are used in the manufacture of many parts of machines and mechanisms. These cast irons are called *grey* or *foundry irons.*

Cast irons containing carbon only in chemical combination with iron reveal a white fracture. They are difficult to machine and are usually converted to steel. They are called *white* or *conversion pig irons.*

Besides white and grey cast iron, so-called *malleable cast iron* is used for casting parts for the tractor, automobile and other industries. It is produced by annealing white cast iron in special annealing furnaces at a temperature ranging from 950 to 1,000° C. By this process, the excessive brittleness and hardness, typical of white cast iron, are greatly reduced. Malleable cast iron, like grey cast iron, cannot be forged, and the term "malleable" only indicates its high ductility.

To increase their strength cast irons are alloyed by introducing nickel, chromium, molybdenum, copper and other elements, and also inoculated by ladle additions of aluminium, calcium or silicon. Cast irons thus obtained are known as *alloyed* or *inoculated* cast irons.

The following grades of cast iron are most widely used:

grey cast iron: grades СЧ00, СЧ12-28, СЧ15-32, СЧ18-36 and others;

malleable cast iron: grades КЧ37-12, КЧ35-10, КЧ33-8, КЧ30-6 and others;

inoculated cast iron: grades МСЧ28-48, МСЧ32-52, МСЧ35-56 and others.

The letters and figures of the cast iron grade indexes denote: СЧ—grey cast iron, КЧ—malleable cast iron, МСЧ—inoculated grey cast iron. The first two figures following the letters indicate the tensile strength, and the

second two show the bending strength, in kgf per square millimetre.

Steel is an alloy of iron and carbon, with a carbon content up to 1.7 per cent.

Compared with cast iron, steel possesses much higher physical and mechanical properties. It has a high tensile strength, good machinability, and can be forged, rolled and hardened. In addition, it is fluid in the molten state, so that various castings can be produced from it. It is therefore widely used in all spheres of national economy, especially in the machine-building industry.

Steel is produced by remelting conversion pig and removing excess carbon, silicon, manganese and other impurities. The melting is conducted by the open-hearth, electrical, Bessemer and Thomas processes.

The most widely used method of producing ordinary grades of steel is the *open-hearth process*, while high-quality steels are produced in *electric furnaces*.

Steel produced from cast iron in steel plants is delivered to rolling or forging shops in the form of ingots. It is then processed into rolled sections or sheets, and into forgings of various shapes and sizes.

All modern steels are classified as follows:

According to chemical composition:

(a) carbon steels;
(b) alloy steels.

According to production method:

(a) ordinary-quality steels;
(b) quality steels;
(c) high-quality steels.

According to application:

(a) structural steels;
(b) tool steels.

Carbon steel is widely used in industry. Its basic component which determines its mechanical and other properties is carbon. Any increase of the carbon content in steel increases its strength and hardness, but reduces its ductility, making it more brittle.

Depending on the purpose for which it is intended, carbon steels are classified as structural steels (carbon content up to 0.65 per cent) and tool steels (carbon content over 0.65 per cent). Structural steels, in turn, are divided into ordinary and quality steels.

Ordinary structural steel is produced by the Bessemer, Thomas or open-hearth processes and is available as rolled steel sheets or sections. It is used for the manufacture of building structures, bolts, pipes, etc., and also for uncritical machine components.

The grade index of ordinary carbon steels consists of the letters Cт., followed by figures from 0 to 6 (Cт. 0, Cт. 1, Cт. 2, and so on). Each increase in the grade number indicates an increase in the carbon content of the steel by one-tenth of one per cent.

Quality structural steel is produced in open-hearth or electrical furnaces. It contains less of the harmful impurities (sulphur and phosphorus), and is used for making heavy-duty parts. Quality steel is delivered as bars, forgings, plates and other sections.

The grade index of quality carbon steel consists of figures 05, 08, 10, 20, 35 and so on up to 65, denoting the average carbon content of the steel in hundredths of one per cent (for example, steel 45 contains an average of 0.45 per cent carbon).

Low-carbon steels, grades 05, 08, 10, 20, are used for manufacturing parts not subject to heavy loads by welding and drop forging. Medium-carbon steels, grades 35, 45, 50, are used for manufacturing spindles, shafts, gears and other parts. Grade 65 high-carbon steel is used for manufacturing wire rope, spiral springs, and other more or less critical parts.

Carbon tool steel is melted in open-hearth or electrical furnaces. It is classed as quality and high-quality steel.

The grade index of *quality tool steel* is the letter У followed by figures indicating the carbon content in tenths of a per cent, for example, У7, У8, У9, up to 13.

High-quality tool steel contains a less amount of harmful impurities (sulphur, phosphorus) than quality steel. The indexes of high-quality tool steels are similar to those of quality tool steel but they are followed by the letter A, for example, У7A, У8A, and so on. High-quality carbon tool steel is used for making various tools (impact, cutting, measuring, etc.).

Alloy steels are steels which, in addition to carbon, contain elements which improve their properties. Such elements are: chromium, nickel, silicon, tungsten, manganese, vanadium, cobalt and others. Depending on the alloy-

ing elements, alloy steels are classified as chromium, nickel, chromium-nickel-tungsten, chromium-nickel, chromium-vanadium and other steels.

Alloying elements impart particular properties to steel, in accordance with its purpose. Their effects on the properties of steel are given below.

Chromium increases the strength of steel, its hardness and its resistance to wear.

Nickel increases the strength, toughness and hardness of steel, its hardenability and resistance to corrosion. Because of its high cost, nickel is added in combination with chromium, manganese and other alloying elements.

A *silicon* content over 0.8 per cent increases the strength, hardness and elasticity of steel, but at the same time reduces its toughness.

Manganese increases the hardness and strength of steel, and improves its weldability and hardenability.

Alloy steel, depending on the proportion of alloying elements, is classified as low-alloy (up to 5 per cent alloying elements), medium-alloy (from 5 to 10 per cent alloying elements) and high-alloy (over 10 per cent alloying elements) steel.

As in the case of carbon steel, alloy steel is classified according to application as structural and tool steel.

According to the U.S.S.R. State Standard, the following letters are used for indicating the alloying elements entering into the composition of steel: X—chromium; B—tungsten; M—molybdenum; Ф—vanadium; K—cobalt; Г—manganese; T—titanium; C—silicon; H—nickel; Ю—aluminium, and Д—copper.

High-quality steels are indicated by the letter A following the grade index.

The grade index of alloy steels consists of a combination of figures and letters. The first two figures indicate the average carbon content in hundredths of one per cent. The letters denote the alloying elements, and the figures after the letters indicate the content of these elements in per cent. Thus, the index 40X indicates a chromium steel containing 0.4 per cent carbon and 1 per cent chromium; 30XH3A—a chromium-nickel steel containing about 0.30 per cent carbon, 1 per cent chromium and 3 per cent nickel, etc.

Structural alloy steels are used for the critical parts of machines and various metal structures. Parts made

from these steels are heat treated to improve their mechanical properties.

Structural alloy steels include: chromium steels (grades 15X, 20X, 30X, etc.), chromium-vanadium steels (grades 15XФ, 20XФ, 40XФA, etc.), molybdenum steels (grade 16M), chromium-molybdenum steels (grades 15XM, 30XM), chromium-silicon steels (grades 33XC, 38XC, etc.), and chromium-nickel steels (grades 12XH2, 12XH3A, etc.).

Alloy tool steel, in comparison with carbon steel, possesses a higher resistance to wear, greater hardenability, increased toughness after hardening and is less susceptible to distortion and cracking during heat treatment.

The cutting properties of alloy steels are about the same as those of carbon steels because of their comparatively low heat resistance, which lies in the region of 200-250° C.

The application of the main types of alloy tool steels is as follows: grade 9XC steel is used for making threading dies, drills, reamers, milling cutters, thread chasers and taps; grade B1 steel—for twist drills, taps, reamers and threading dies; grade XB5 steel—for lathe, planer and engraving tools, for milling cutters and other tools; grade XBΓ steel—for long taps and reamers, special milling cutters and other tools.

High-speed tool steel was introduced for making cutting tools at the beginning of the 20th century, and was so called because of its high cutting properties.

High-speed tool steel differs from carbon and alloy steels by its higher heat resistance, due to its high tungsten content. Tools made from high-speed steel retain their cutting properties when heated to 550-600° C during the cutting process.

The main grades and the chemical compositions of high-speed tool steels are given in Table 1.

Grade P9 and P18 high-speed tool steels are most commonly used for the manufacture of the widest range of cutting tools.

4. Nonferrous Metals

In spite of their high cost nonferrous metals are widely used in industry. They possess many natural properties which are absent in ferrous metals.

Table 1

Chemical Composition of the Chief Grades of High-Speed Steels

Grade of steel	Chemical composition, per cent										
	Carbon	Manganese	Silicon	Chromium	Tungsten	Vanadium	Cobalt	Molybdenum	Nickel	Sulphur	Phosphorus
		maximum						maximum			
P18	0.7-0.8	0.4	0.4	3.8-4.4	17.5-19.0	1.0-1.4	—	0.3	0.4	0.03	0.03
P9	0.85-0.95	0.4	0.4	3.8-4.4	8.5-10.0	2.0-2.6	—	0.3	0.4	0.03	0.03
P9Φ5	1.4-1.5	0.4	0.4	3.8-4.4	9.0-10.5	4.3-5.1	—	0.3	0.4	0.03	0.035
P14Φ4	1.2-1.3	0.4	0.4	4.0-4.6	13.0-14.5	3.4-4.1	—	0.3	0.4	0.03	0.035
P18Φ2	0.85-0.95	0.4	0.4	3.8-4.4	17.5-19.0	1.8-2.4	—	0.3	0.4	0.03	0.03
P9K5	0.9-1.0	0.4	0.4	3.8-4.4	9.0-10.5	2.0-2.6	5.0-6.0	0.3	0.4	0.03	0.03
P9K10	0.9-1.0	0.4	0.4	3.8-4.4	9.0-10.5	1.0-2.6	9.5-10.5	0.3	0.4	0.03	0.03
P10K5Φ5	1.45-1.55	0.4	0.4	4.0-4.6	10.0-11.5	4.3-5.1	5.0-6.0	0.3	0.4	0.03	0.035
P18K5Φ2	0.85-0.95	0.4	0.4	3.8-4.4	17.5-19.0	1.8-2.4	5.0-6.0	0.3	0.4	0.03	0.03

Nonferrous metals include copper, aluminium, tin, lead, zinc, magnesium and others.

Copper is a red coloured metal with a specific weight of 8.93; it melts at 1,083° C.

The most valuable properties of copper are its high electrical conductivity, plasticity, thermal conductivity, and relatively high corrosion resistance.

Copper is used mainly in the electrical-engineering industry, but is also used in producing many alloys used in machine building.

The main grades of copper are: M0, M1, M2, M3, and M4.

Aluminium is a light, silvery-white metal having a specific weight of 2.7 and a melting point of 658° C. It is a very good conductor of electricity, has good plasticity and corrosion resistance, melts easily, can be hardened, mechanically worked and rolled into thin foil.

Aluminium is used for making electric wires, domestic utensils and foils. It is also used in the production of many alloys for the construction of aircraft, cars and railway carriages, and in the radio industry, etc. Aluminium is rarely used in its pure form because of its poor mechanical properties.

The main grades of aluminium are: AB0000, AB000, AB00, and AB0.

Tin is a silvery-white brittle metal with a specific weight of 7.3 and a melting point of 232° C. It is used mainly for tinning, the production of solders, and in babbitts and bronzes.

The main grades of tin are: O1, O2, O3, and O4.

Lead is a bluish-grey soft metal with a specific weight of 11.34 and a melting point of 327° C. It is easily rolled. Lead is used for producing such alloys as bronzes, babbitts and solders.

The main grades of lead are: CB, C0, C1, and C2.

Zinc is a white metal with a bluish tint; it has a specific weight of 7.14 and a melting point of 419° C. It can easily be mechanically worked and possesses many technical features permitting its wide use as a substitute for copper, tin and their alloys.

Zinc is used as semifinished products, rods, pipes, bars, strips and wire, obtained by mechanical working; it is also used for alloying other metals.

The main grades of zinc are: ЦВ, Ц0, Ц1, Ц2, Ц3, and Ц4.

Magnesium is a lustrous white metal with a specific weight of 1.74. It is ductile, and has a melting point of 650° C.

Magnesium is used for the production of light alloys possessing high mechanical properties (alloys with aluminium, manganese, zinc). These are used in aircraft construction.

The main grades of magnesium are: M1, and M2.

5. Alloys

Nonferrous alloys. As already stated above, nonferrous metals such as copper, aluminium, magnesium and others, find limited application in their pure form. To improve their mechanical, processing and other properties, nonferrous metals are alloyed to produce: brass, bronze, aluminium, magnesium, antifriction (babbitt) and other nonferrous alloys.

The following nonferrous metal alloys are most widely used in industry:

Brass is an alloy of copper and zinc. It has greater strength, ductility and hardness than pure copper, and has higher resistance to corrosion and greater fluidity in the molten state. Brass is manufactured as sheets, wire, bars, etc., and is used for the manufacture of cast and forged fittings, vessels, etc.

The main types of brasses include: *casting brasses* (for foundry use) and *wrought brasses*.

The grade index of brass consists of the letter Л followed by a figure indicating its copper content in per cent. For example, the copper content of grade Л62 brass is about 62 per cent.

In addition to ordinary brass, special brasses, containing iron, manganese, nickel, tin, etc., are used. Some brasses are not inferior to carbon steel in strength.

Special brasses are designated with an index consisting, in addition to the letter Л, of conventional symbols denoting the different alloying elements, e.g.: Ж—iron; Мц—manganese; Н—nickel; О—tin; К—silicon; and С—lead. The content of these elements, in per cent, is indicated by the figures following the letters. For instance,

ЛЖС58-1-1 denotes an iron-lead brass containing 58 per cent of copper, 1 per cent of iron, and 1 per cent of lead.

The most frequently used types of brass are: ordinary brasses, grades Л62, Л68; special brasses, grades ЛМц58, ЛС59-1, ЛО62-1, and others.

Bronze is an alloy of copper and other nonferrous metals (except zinc).

Tin bronze has an increased corrosion resistance, high fluidity in the molten state and possesses good antifriction properties. It is mainly used for casting bearings and other similar parts, and is designated by the letters БрО followed by figures, indicating the tin content, in per cent.

The main grades of tin bronze are: БрО10, БрО14 and БрО20.

Aluminium bronze, as compared with tin bronze, possesses higher ductility, and resistance to corrosion and wear; its casting properties, however, are inferior.

The addition of iron, nickel and manganese to aluminium bronze increases its corrosion resistance and improves its mechanical properties. Such bronze is used for manufacturing shaped castings, fittings, gears and other parts.

The main grades of aluminium bronze are: БрАЖ9 and БрАЖН10-4-4.

Manganese bronze has a higher ductility and good resistance to corrosion, but has comparatively poor mechanical properties and is used mainly for making steam fittings.

The main grade of manganese bronze is БрМц5.

Silicon bronze is characterized by its high ductility and good casting properties. Manganese is added to increase its resistance to corrosion, and lead to improve its antifriction properties.

Silicon bronze is used for making spring contacts, wire, etc.

The most commonly used grade of silicon bronze is БрКМц3-1.

Leaded bronze possesses good antifriction properties. Grade БрС30 leaded bronze is used for casting bearing bushings.

Beryllium bronze possesses high elasticity, hardness and resistance to wear. Grade БрБ2 beryllium bronze is used for manufacturing springs, wear-resisting parts, etc.

Silumin is an alloy of aluminium and silicon; it has good castability and is widely used for manufacturing all

kinds of castings. It has superior mechanical properties and a higher specific gravity than aluminium.

The main grades of silumin are: АЛ2, АЛ4, and АЛ9.

Duralumin is an alloy of aluminium, copper, magnesium and manganese. Copper and magnesium increase the strength of the alloy after heat treatment, while manganese increases its hardness and resistance to corrosion.

Duralumin is heat treated to improve its mechanical properties, which then approach those of medium-carbon steel. This alloy is especially widely used in the aircraft industry.

The main grades of duralumin are: Д1 and Д16.

Magnesium alloys are alloys of magnesium, aluminium, zinc, manganese and other elements. The casting properties of magnesium alloys are inferior to those of aluminium, but because of their low specific weight they are widely used in aircraft construction, the radio industry, etc.

The strength of magnesium alloys can be increased by heat treatment.

The main grades of magnesium alloys are: МЛ4, МЛ5.

Babbitts are lead- or tin-base alloys. They have a low coefficient of sliding friction when working together with other metals. These alloys are called *antifriction* alloys.

Tin-base babbitts, which contain antimony, copper and tin, are used for casting bearings working under high impact loads.

Lead-base babbitts, in addition to lead, contain antimony, tin and copper. They are used in bearings for metal-cutting machine tools, electric motors, automobiles, etc.

The main grades of babbitts are: Б83 and Б16.

Hard alloys (cemented carbides and cast cutting alloys) have been widely used in industry during the last 25 years, especially in the mining industry for making boring tools, in machine building for cutting, pressworking, wire drawing and for dressing grinding wheels and, also, for facing surfaces subject to wear.

Carbide-tipped tools have a considerably longer life than ordinary tools; their use greatly increases the output of equipment and lowers production costs.

Cemented carbides are made from extremely fine grains of tungsten and titanium carbides, cemented together with cobalt, which acts as a bonding agent.

Carbides are chemical compounds of carbon with metals and some metalloids (silicon, boron). They impart to alloys increased hardness, approaching that of the diamond (for instance, boron carbide), and increased resistance to abrasion. Metal-ceramic alloys are the most widely used cemented carbide alloys.

Cemented carbides are used as tips brazed on to such cutting tools as cutters, drills, reamers, etc., and also for dressing grinding wheels, for heading tools, facing dies and punches, and for processing and cutting glass, etc.

These tips are produced by thoroughly mixing the powdered components and compacting the mixture with a pressure of 1,000 to 4,200 kg/cm^2. The semifinished products obtained in the moulds are then sintered in electric furnaces at a temperature of from 1,400 to 1,500° C. The bonding metal (cobalt) melts during this process, envelops the carbide grains and thus binds them together.

Carbide-tipped tools are used today for machining metals at high speeds.

Cemented carbides are exceedingly hard (R_A=87-91 kg/cm^2) and retain their cutting properties at temperatures of from 1,000 to 1,100° C without any apparent wear. They can machine hardened steel, chilled cast iron, granite, etc.

Two groups of cemented carbides are produced in the Soviet Union—*TK titanium-tungsten cemented carbides* for machining steels, and *BK tungsten cemented carbides* for machining cast irons, nonferrous metals, their alloys and nonmetals. Each group, in turn, is classified into grades which denote their scope of application:

titanium-tungsten cemented carbides—grades T5K10, T14K8, T15K6, T15K6T, T30K4, and T60K6;

tungsten cemented carbides—grades BK2, BK3, BK4, BK6, BK6M, BK8, BK10, BK11, and BK15.

Cast and powdered cutting alloys are often used for hard facing parts subject to wear and tools to increase their surface hardness and to improve their wear resistance. Hard facing or surfacing is effected with a welding torch in an oxy-acetylene flame or by a d-c electric arc.

Stellite, stellite-type alloys, sormite, stalinit, rhelit and similar cast cutting alloys are used for hard facing.

Ceramics (ceramic-tool materials) are mostly made from aluminium oxide, and are also sintered at high tem-

peratures. They contain no tungsten, cobalt and other expensive elements.

These materials possess great hardness *, high specific gravity, and a high red hardness (up to 1,200° C) which allows work to be carried out at high cutting speeds. But their mechanical strength is low. They cannot withstand impact loads and vibration. Metal-cutting tools tipped with ceramics (grade ЦМ-332) are used for semifinish and finish turning of cast iron, structural and alloy steels.

6. Heat Treatment and Casehardening of Steels

Heat treatment of steel. By *heat treating* is meant the process of heating a metal to a definite temperature, holding it at this temperature and subsequently cooling it at a predetermined rate. This process does not change the

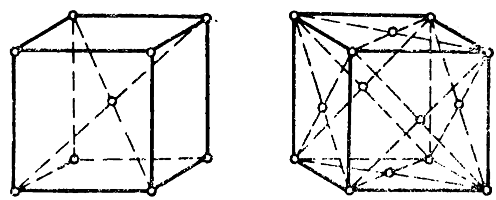

Fig. 1. Crystal lattice structure:
(*a*) alpha-iron, (*b*) gamma-iron

chemical composition of the metal, but does alter its structure and mechanical properties.

The structure of a metal can be determined from its fracture. A large number of grains, bound together, may be seen on the fracture surface. Each of these grains consists of minute particles, atoms, which are arranged in a definite order to form a crystal lattice. The atoms change their arrangement on heating, the change depending on the temperature.

When iron is heated to a temperature of 910° C, its atoms arrange themselves in the shape of a cube, forming a bodycentred crystal lattice of alpha-iron (α-iron) in which eight atoms occupy the corners of the lattice and

* The hardness of ceramic-tool materials is not inferior to that of cemented carbides ВК8 and Т15К6.

one—the centre (Fig. 1*a*). On heating the iron above 910° C, the atoms of the crystal lattice regroup into a fourteen-atomed facecentred cube, forming a lattice of gamma-iron (γ-iron) (Fig. 1*b*).

In steels the transformation of α-iron into γ-iron takes place at a lower temperature (723° C), than in pure iron. If the heated metal is cooled slowly, the rearrangement of the crystal lattice proceeds in the reverse order.

The properties of a metal depend on the arrangement of the atoms in the crystal lattice. In annealed steel, the iron is in the α-state and is called *ferrite*. The carbon, however, is chemically combined with the iron as *cementite* (iron carbide). Ferrite is tough, while cementite is extremely hard and brittle. The structure in which cementite grains are uniformly distributed in ferrite is called *pearlite*. The solid solution of carbon in iron which occurs at high temperatures, is called *austenite*. The structure of hardened steel obtained after rapid cooling (quenching) is called *martensite*; it is very hard and brittle.

There are several kinds of heat treatment: annealing, normalizing, hardening and tempering, surface hardening, and cold treatment.

The main object of *annealing* is to reduce the hardness in order to facilitate machining and to relieve internal stresses in steel. The annealing temperature depends on the carbon content. Steel with a carbon content over 0.8 per cent is annealed at 750-760° C, and steel with a lower carbon content is heated gradually to 930-950° C.

After heating, the metal is cooled slowly in the furnace. In the annealed state the steel acquires a pearlite structure.

The object of *normalizing* is to improve the structure of steel, remove internal stresses and ensure better machinability. It differs from annealing in that cooling takes place in still air instead of in the furnace.

After normalizing, the steel acquires a pearlite structure, but with a finer grain and more uniform structure. The hardness and strength of normalized steel is higher than that of annealed steel.

Hardening involves heating the steel to a definite temperature, holding it at this temperature a certain time, and then rapidly cooling it in water, oil, molten salts or in air. Hardening is followed by tempering to increase the

hardness and strength of steel and its resistance to abrasion.

Carbon and alloy steels are heated in electric furnaces or in salt baths for hardening.

As a result of hardening, the steel acquires a fine-grained structure, consisting predominantly of martensite—the hardest and most brittle structure.

As a result of rapid cooling during hardening internal stresses will be induced which may cause cracks, warping and brittleness. These defects are reduced by the next heat treatment operation known as tempering.

Tempering involves heating the steel to a temperature considerably lower than the hardening temperature, holding it at this temperature and cooling.

Carbon and alloy steels are tempered at a temperature of 150-250° C, high-speed steels—at 550-580° C. They are cooled in air.

Surface hardening consists in heating the surface of a steel part to a definite temperature (hardening temperature) followed by rapid cooling. This results in an exceedingly hard, comparatively shallow layer (from 0.3 to 10 mm) on its working surfaces without altering the structure and hardness of the internal mass of metal in the part. This is especially valuable for parts working under stress (engine crankshafts, gears, etc.), requiring a high hardness of the parts subject to friction combined with a resilient (nonbrittle) core.

Induction surface hardening is conducted in special high-frequency installations by means of heating coils, through which high-frequency currents are passed.

Induction surface hardening ensures good quality and is, therefore, widely used in industry.

Cold treatment is a modern method of treating steel. It consists in raising the hardness and abrasion resistance of the steel by transforming the residual austenite in hardened steel into martensite. The treatment is carried out in special installations which produce subzero temperatures.

The object of **casehardening** is to alter the chemical composition and properties of the surface layers of steel, and to increase the surface hardness, and resistance to abrasion and corrosion. This is achieved by the diffusion of certain elements from an external medium into the surface of the metal.

Casehardening processes include: carburizing, nitriding, cyaniding, and calorizing.

Carburizing is the saturation of the surface of steel with carbon, at a temperature of 880-950° C, with subsequent hardening. The aim is to obtain an extremely hard and abrasion-resistant surface.

Carburizing is applied to components of low-carbon steel with a carbon content of 0.1-0.25 per cent. On saturation, the carbon content of the surface may be increased to 1-1.25 per cent. Carburizing is usually performed after machining with an allowance left for finish grinding.

Nitriding is the saturation of the surface of steel with nitrogen, by heating the steel to 500-700° C in ammonia.

Nitriding is usually applied to steels containing aluminium, chromium and molybdenum, in order to raise the hardness, abrasion and corrosion resistance of the surface layer.

Cyaniding is the simultaneous saturation of the surface of steel with carbon and nitrogen at a temperature of 530-550° C. It can be performed in a liquid, solid or gaseous medium. In the latter case it is called carbonitriding.

The object of cyaniding is to increase the life of twist drills and other high-speed cutting tools and of intricately shaped parts.

Calorizing is the saturation of the surface of steel with aluminium diffused from media containing aluminium.

Calorizing results in high scale resistance (at temperatures up to 800-850° C). Gas producer combustion chambers, thermocouple sheaths, pouring ladles, etc., are generally calorized.

7. Corrosion of Metals and Protective Coatings

Corrosion is a destructive process resulting from the chemical and electrochemical interaction between a metal and the surrounding medium. Corrosion gradually destroys the surface of parts and buildings, leads to the formation of cavities, and can also completely transform a metal. For instance, thin sheets of metal may be entirely converted into oxides—rust.

Metal losses due to corrosion are considerable and highly detrimental to national economy. Under ordinary

conditions, corrosion takes place under the action of water and oxygen. Several types of corrosion are known, the most destructive of which are chemical and electrochemical corrosion.

Chemical corrosion is due to the reaction between a metal and a medium not conducting electric current. Such a medium may be a gas or organic matter, for instance oil. This reaction results in the formation of chemical compounds on the surface of the metal, usually as oxide films.

Electrochemical corrosion results from the contact between a metal and a liquid conducting electric current and called an electrolyte. Such liquids may be acids, alkalis, salt solutions, soil water, etc.

The chief methods of protecting metals against corrosion are:

(1) metallic coatings;
(2) nonmetallic coatings;
(3) chemical coatings.

Metallic coatings. The metal to be protected against corrosion is coated with a thin film of another metal, possessing better anticorrosion properties. Metallic coatings are applied by the following methods: hot-dip, electroplating, diffusion, metallizing (spraying) and others.

In the *hot-dip method* the coating is formed by immersing the parts to be coated in a bath of molten metal. Zinc coating (galvanizing), tinning, lead and aluminium coating are performed by this method.

The *electroplating method* consists in depositing a thin layer of metal onto the surface of an article by the electrolysis of solutions of zinc, tin, lead, nickel, chromium and other metal salts.

The advantage of this method is the possibility of depositing a protective coating of any metal to any required thickness (from 0.005 to 0.030 mm) without heating the article. Chromium, nickel and zinc are some of the most commonly used plated coatings.

In the *diffusion coating method* the metal surface absorbs a protective metal, which impregnates it at high temperatures. Chromizing, siliconizing, etc., are performed by this method.

Metallizing (metal spraying) is the method of spraying a thin layer of molten metal onto an article by a special gun.

Nonmetallic coatings. Protection against corrosion is achieved by coating articles with varnishes, paints, enamels and grease. The purpose of these coatings is to isolate the metal from the action of the surrounding medium.

Paint and varnish coatings constitute about 65-70 per cent of all anticorrosion coatings. The disadvantages of these coatings are their insignificant mechanical strength and tendency to burn at high temperatures.

Chemical coatings are based on the process of forming protective films, usually oxides, on the surface of articles. Such processes include the oxide coating, bluing and steam treatment processes.

Oxide coating implies the immersion of the articles in solutions of nitrates at about 140° C.

Finished tools or components of machines are treated by steam to increase their resistance to corrosion and to prolong the service life of their working surfaces. They are subjected to steam treatment after heat treatment and finish machining, including grinding and lapping. The steel articles, heated to 400-600° C, are oxidized by steam, and a characteristic oxide film is formed on their surface.

They are tempered at the same time—the stresses developed during the preceding operations are removed. The oxide film acts as a hard lubricant and helps to increase the resistance to abrasion and corrosion of the steel.

8. Nonmetallic Materials

Together with metals, nonmetallic materials are widely used in all branches of industry. They include plastics, rubber, chemicals, moulding sands, textiles, wood, paints and varnishes, and other materials. Special mention should be made of plastics which are finding ever-increasing application in industry.

Plastics are based on natural and synthetic compounds. They can be moulded when heated or subjected to pressure, and can retain their new shape under normal conditions. Plastics consist of:

(1) various fillers (wood flour, fabric, paper, glass fibres, cotton combings, etc.) for increasing strength;

(2) bonding agents—natural and artificial resins (phenol-formaldehyde resins);

(3) dyes;

(4) plasticizers, for improving the plasticity and elasticity of the plastic products, and also a number of other accessory materials.

Most articles made of plastics are produced by *compression moulding* in metal moulds or by *injection moulding*. For this reason they require no subsequent machining. Laminated plastics produced in the form of rods or sheets are used for the manufacture of articles by machining.

Articles made from plastics have a low specific weight, sufficient strength, and good anticorrosion and dielectric properties. They are considerably cheaper than metal articles.

Plastics are used as substitutes for critical nonferrous metals and alloys used in the production of electrical equipment, gears, bushings, facing of drawing dies and also in the manufacture of large-size articles (car bodies, etc.).

The most important plastics used in industry include: laminated fabric (containing textile waste), hetinax (hardened paper), lignofol (compressed wood), delta-wood (moulded impregnated wood), fibre glass reinforced plastics, polyethylene, polystyrene, aminoplastics, carbolite, fibre-filled moulding material and various polymers.

Abrasive materials (or simply abrasives) form a large group of very important nonmetallic engineering materials. They are exceedingly hard fine-grained or powdered materials, and are used for processing the surfaces of metals minerals and other materials.

Abrasives are classified as *natural* abrasives (quartz, emery, corundum, diamond, flint, garnet, pumice and others) and *manufactured* abrasives (aluminium oxide, silicon carbide and boron carbide).

Manufactured abrasives are most frequently used in the engineering industries.

The basic requirements for abrasive materials are:

(1) hardness, strength and toughness;
(2) shape of abrasive grain;
(3) abrasive power;
(4) grain size.

Abrasive materials possess *great hardness*, inferior only to diamonds, e.g., the microhardness of various types of aluminium oxide ranges from 1,800 to 2,600 kg/mm^2, of silicon carbide from 2,800 to 3,300 kg/mm^2, of boron carbide 3,700 kg/mm^2, and of the diamond 10,060 kg/mm^2.

Abrasive tools (grinding wheels, sticks, segments, points) are classified by their hardness (or grade) into soft (designated by letter M), medium soft (CM), medium (C), medium hard (CT), hard (T), very hard (BT) and extra hard (ЧТ)*.

Abrasive materials have a *high heat resistance* (1,800-2,000° C) and are acid resistant, but in comparison with metals and alloys they possess much lower compressive, and especially bending strength.

The term "*grit*" is used to indicate the size and uniformity of the abrasive particles and is usually expressed by figures indicating the number of meshes per linear inch of a sieve through which the abrasive particles will pass.

Abrasive tools are made of abrasives with various grit sizes depending on the type of grinding work, and the precision and surface finish required. The basic grit size numbers are: 24, 36, 46, 60, 80, 100, 120, 150, 180, 220, 240, 280, 320.

By *abrasive power* is understood the amount of material removed before the abrasive grains wear out. Working of materials by abrasive tools is characterized by the simultaneous action of a large number of cutting edges of the abrasive grains, which thereby ensure a sufficiently high productivity.

Abrasive tools are made by binding the abrasive grains with bonding agents, or bonds. The main bonding materials used in the Soviet Union are: vitrified bond (symbol K), resinoid bond (Б) and rubber bond (B).

The abrasive industry of the Soviet Union produces all the abrasives that the country needs, aluminium oxide containing 92-94 per cent alumina, accounting for 75 per cent of the total output. Aluminium oxide is very hard and tough. It is classified as: standard (symbol Э) and white (ЭБ) types. Both are used for machining steels, cast iron, tough bronze, etc.

Silicon carbide abrasives are used for grinding cemented carbides, grey cast iron, copper, aluminium and other metals and alloys, possessing low tensile strength. It is available as the green (symbol K3) and black (KЧ) types.

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* The term hardness, or grade, as applied to a grinding wheel, refers to the tenacity with which the bond holds the grains in place, and not to the hardness of the abrasive.

Boron carbide (in powder form) is used for lapping carbide-tipped cutting tools, for polishing precious stones, etc.

9. Auxiliary Materials

Auxiliary materials include lubricants, cutting fluids, wiping materials, etc.

Mineral, vegetable and animal oils are used as lubricants. Cutting fluids, used in the machining of metals, include soap water, soda water and soluble oil emulsions. They are sometimes called coolants.

Oils are usually used for lubricating machines and mechanisms to reduce friction, and also as cutting fluids. When drilling, enlarging and reaming holes in carbon and alloy steels, emulsions, and more rarely vegetable oils, are used as coolants, while emulsions, sulphurized oils and vegetable oils are used for threading and tapping operations.

Cotton waste and rags are used for removing small shavings and oil from the machine tools, and for wiping tools and machine parts.

Chapter III

DRAWINGS AND HOW TO READ THEM

1. Drawings and Their Importance in Engineering

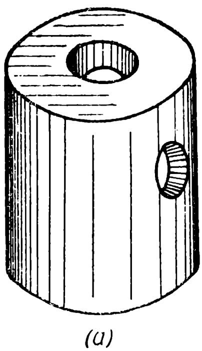
To make an object, you have to know its shape and dimensions. An object with a simple, familiar shape can be made from its description. For example, it is required to make a cylindrical ring with an outer diameter of 20 mm, internal diameter 10 mm and a height of 5 mm. This information is quite sufficient for a worker, familiar with a ring, a cylinder, and who knows what a diameter is, to make such a ring. But an object of intricate (or unfamiliar) shape, having many dimensions, cannot be made from its description alone. In this case we must have a picture showing its shape and dimensions.

An object can be represented as we see it (in three dimensions), in a sketch or a photograph; these, however, distort its shape and dimensions to a certain extent, and usually give no idea of its design. Therefore a sketch or a photograph, with dimensions shown on it, will be satisfactory only for making the simplest objects.

In order to manufacture an intricate object it is necessary to represent it without distorting its shape, the proportion and location of its parts, and its construction, i.e., so that a circle remains a circle, a right angle remains a right angle, parallel straight lines—parallel, and so on. These requirements are satisfied by representing an object with the aid of a drawing in which the object can be shown from different sides—in several views or projections, where each view (or projection) depicts the object from one side only. In addition to this, the construction of the object is shown by sections and revolved sections.

If the sketch of a cylinder, shown in Fig. 2*a* is compared with its drawing (Fig. 2*b*) the advantage of drawings over sketches will be obvious.

From the sketch it is impossible to determine, for instance, the number of holes in the cylinder, their depth, and so on. In the drawing the cylinder is represented by two accurate geometrical figures—a rectangle and a circle, which are the corresponding projections of the side surface (in section) and the base of a cylinder.



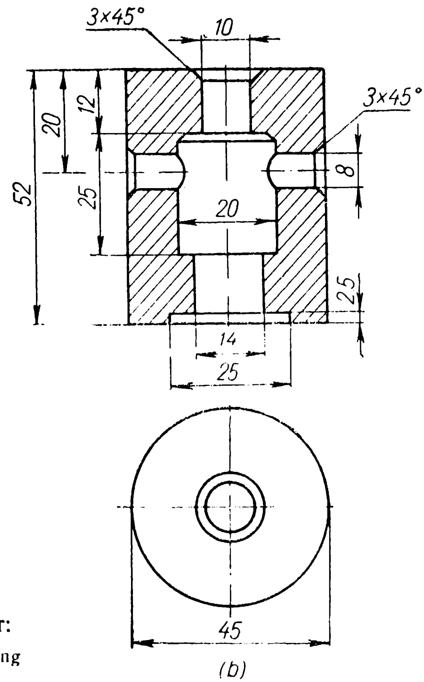


Fig. 2. Cylinder:
(a) sketch, (b) drawing

These projections completely represent both the exterior and the interior construction of the cylinder.

Thus a *drawing* is the image of an object (or of its part) on a plane. It reproduces the shape fully and exactly, and also contains all the information necessary for its manufacture and inspection.

The ability to read a drawing correctly ensures that the object will be properly made, lightens work, facilitates increased production and helps workers to improve their skill. A knowledge of the drawing rules and methods employed by designers and draftsmen is essential for a correct and thorough understanding of drawings.

2. The Essence of Orthographic Projections

The views (projections) of an object are arranged on an engineering drawing in a definite order, according to the method of orthographic projections. The main, or front view is given in the centre of the drawing. To its right is the left-hand view, and to its left—the right-hand view. Below, under the main view, is the plan, or top view; over the main view is the bottom view. To the right of the left-hand view is the rear view. In other words, each view (eccept the front and rear views) on the drawing is opposite the side of the object it depicts.

It is not always necessary to give all the above-mentioned views. For the drawing of a simply shaped object, two or three views will sometimes be sufficient, and even one view (for instance, when making a drawing of a flat part made from the sheet material). At the same time, these six coordinated main projections may not always be enough for representing an object of intricate shape. An unlimited number of auxiliary projections may have to be constructed (including sections, revolved sections, etc.). While the locations of the main projections, described above, are compulsory for any number of projections, from two to six, auxiliary projections may be located in any free space on the drawing. The relative positions of the six main projections on a drawing are specified by the rules of orthographic projection, which are described below.

Imagine two planes (for example, two sheets of paper), one vertical and the other horizontal. Let us denote the first, the vertical plane, by the letter V (Fig. 3*a*), and the second, the horizontal plane, by the letter H. Plane V is called the *vertical* plane of projection, and plane H—the *horizontal*. Line OX, on which these planes intersect, is called the *axis of projection*.

In the space in front of the projection planes let us place (suspend) a rectangular box and look at its front side (face) B exactly at a right angle. * We shall see only

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* Since the observer's line of sight is directed at a right angle to the object viewed, this method is called the method of rectangular orthographic projection.

this face of the box, all its other sides being invisible to us. Since face B of the box is a rectangle, let us obtain its image on the vertical projection plane V by dropping perpendiculars from the corners of the face B onto the plane V, joining the points of intersection of these perpendiculars with plane V by straight lines. By doing so,

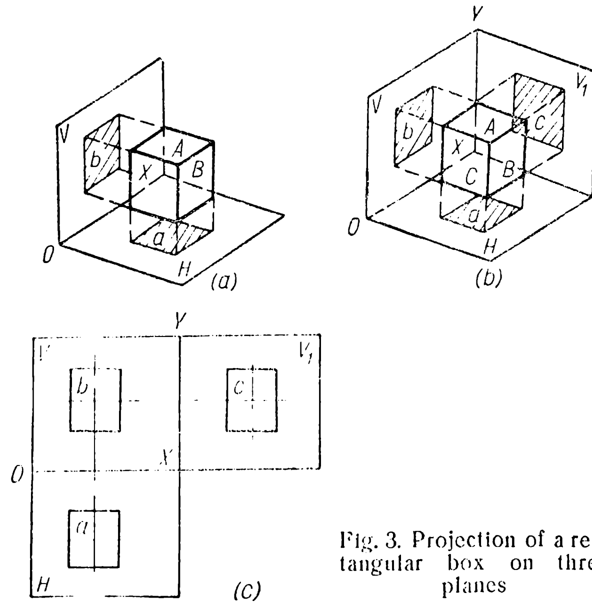

Fig. 3. Projection of a rectangular box on three planes

we obtain projection b of the front face of the box (the *front* or *main view*) on the plane of the projection.

In the same way let us construct the projection of the top face A on the horizontal plane of projection, looking at this face also exactly at a right angle, but from above. The resulting projection a will be the *top view*, or *plan*, of the box.

Now, if we add another plane of vertical projection to the two existing planes V and H in such a way as to form a continuation of the plane V, to the right, we shall obtain a *side projection plane* V_1 (Fig. 3*b*). Line XY, on which the two vertical projections intersect, will be the *second axis of projection*. Let us now construct a projec-

tion on this plane of the left side of the box; this projection c will be the *left-hand view*.

Next, let us unfold all three projection planes into one horizontal plane, along the axes OX and XY. We thus obtain a drawing of the box in the three basic coordinated projections—its front view, plan and left-hand view (Fig. 3c). These three views will be sufficient for depicting such a simple object as a box *, since its other sides do not differ in any way from those shown, i.e., the right-hand view does not differ from the left-hand view, the bottom view from the plan or the back view from the front view.

But three projections will be unsufficient for depicting an object having an intricate shape in which each side differs from the others; in this case it will be necessary to construct a larger number of projections.

In order to understand how these other projections are constructed, let us imagine that the object is placed inside a cube, the sides of which form six projection planes (Fig. 4a) **.

Using the methods described above, let us construct all six views of the object on these projection planes. In addition to the three views on the planes of projection V, H and V_1, as described in the previous example, we shall also obtain: the right-hand view on the left-hand plane of projection; the bottom view on the top horizontal plane of projection; the rear view on the front projection plane.

After this, by unfolding the cube sides along the axes of projection OX, MY, YX, PK and MO, we shall obtain the drawing of the object in six main coordinated projections (Fig. 4b).

Thus, the number of views shown on the drawing depends on the shape of the object.

Usually designers and draftsmen make it a rule to keep the views as few as possible and yet sufficient to give all necessary information about the object.

For a better understanding of the rules for locating the projections in the above examples, the planes and axes of projections were denoted by letters and each view

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* In this case a box can be shown in only two projections.

** For better illustration, the cube sides are shown in Fig. 4a cut and opened.

was given its corresponding name. All this, however, as well as the lines separating the planes of projection (the

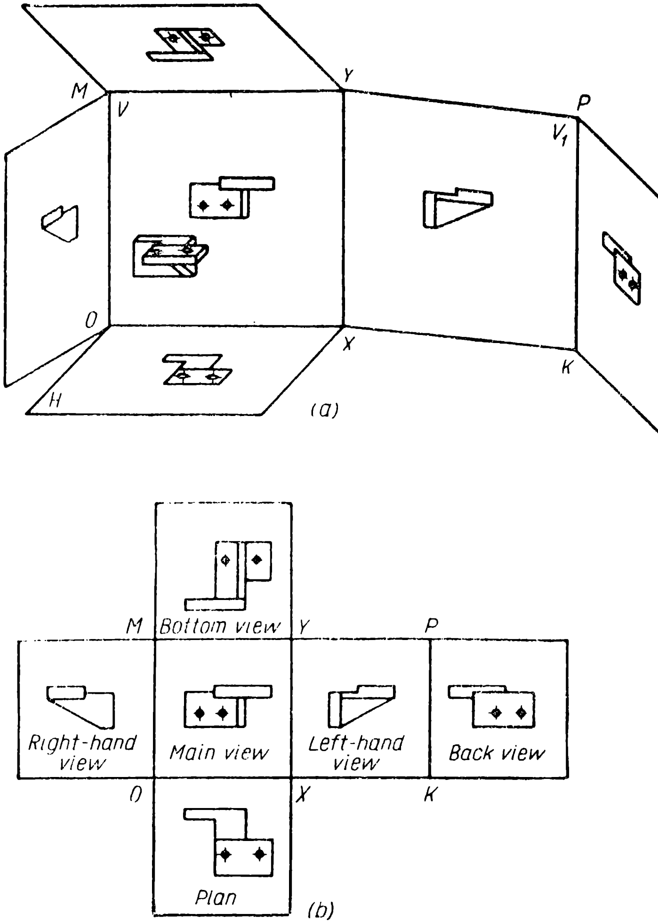

Fig. 4. Projection of a part of complicated shape on six planes

axes of projection) are not shown in working drawings. Only the rear view is always accompanied by a corresponding inscription or an indication of the direction of projection (for example, "View *A*").

Similar indications are made when locating other projections without observing these rules or if in addition to the main projections we give a projection of a part of the surface of the object. In these cases an arrow showing the direction from which the view is drawn, and accompanied by a corresponding letter, is placed near the auxiliary view.

Knowing the rules for locating projections on drawings we can easily find individual elements, lines and

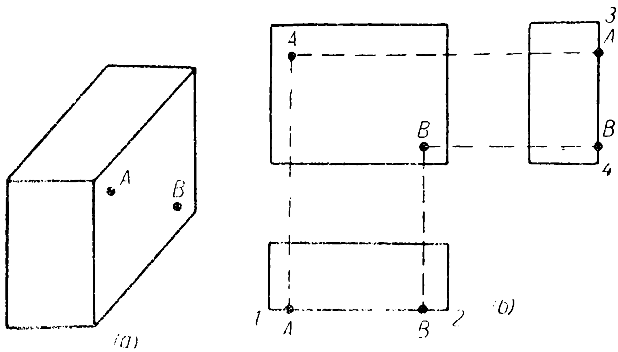

Fig. 5. Projections of points located on one side of a block

points of the depicted object in all its views. This is very important for reading drawings.

Thus, with the aid of these rules, let us try to find on the plan and left-hand view projections of points *A* and *B*, which are marked on the front side of the block shown in Fig. 5*a*. To do this, let us first make a drawing of the block in three projections (Fig. 5*b*), taking for the main view (front view) the front side of the block on which the points are marked. The front side is shown by line *1-2*, and points *A* and *B* will therefore be projected onto this line. In the left-hand view, the front side is again not fully visible and is shown by line *3-4*, on which the projections of points *A* and *B* are located. We have thus located the position of points *A* and *B* on all three projections of the drawing.

Now let us take a case where points *A* and *B* are marked not on one, but on two sides of a block: point *A* on the top; point *B* on one of its sides (Fig. 6*a*). Let us

show the box in the drawing in three projections again, and see where these points will be located. As seen in Fig. 6*b*, point *A* will be located in the plan, and point *B* in the left-hand view. In the main view, the plan will appear as line *1-2* with the projection of point *A* on it; in the left-hand view, the plan will appear as line *3-4*, and the second (side) projection of point *A* will be located on this line.

The projections of point *B* on the front view and the plan can be found in the same way.

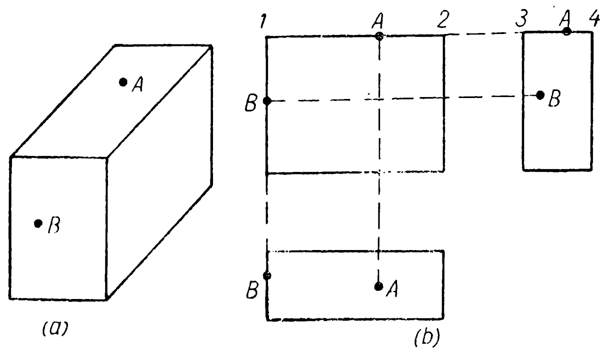

Fig. 6. Projections of points located on two sides of a block

From these examples it can be deduced that to find the points of an object on the projections of a drawing it is necessary to:

(1) determine which projection shows the side of the object on which these points are marked;

(2) ascertain how this side appears in the other projections;

(3) find the position of the projections of the points in the other views by dropping perpendiculars onto the latter from these points.

Projections of the outlines of an object are found by the same principle. Characteristic points determining the location of the lines in the views (points at the beginning and end of the lines, of curves, changes in direction, and so on, between which the projection of the whole line is included) are projected first. Lines are drawn to connect these points, and the projections in the various views are thus obtained.

Projections of separate elements of an object are located by finding the projections of the outlines of each element.

3. Main Types of Engineering Drawings and Rules for Their Construction

Now that we are familiar with the principles of depicting objects on drawings by the method of orthographic projections, let us consider *engineering drawings*, the rules for their construction and the conventions observed.

In all modern enterprises, the basic technical document, to which objects are manufactured, is the shop drawing. Besides depicting the object, it also specifies the dimensions of the object and its elements, the material to be used, gives the requirements which the finished product must meet. All the other technical documents necessary for the technological process (process sheets, instructions, specifications and special engineering requirements, etc.) are drawn up from the information given by the drawing.

In accordance with the stages of the production process (production of blanks and parts, assembly of articles, etc.), and also depending on their purpose and use, U.S.S.R. State Standard (GOST 5291-50) classifies all engineering drawings into the following groups:

basic production drawings, depicting the products manufactured by the given enterprise and their components;

auxiliary production drawings, drawings of special tools, jigs and fixtures, patterns, moulds, etc., designed for basic production;

processing drawings, showing blanks, and also drawings for the execution and inspection of separate processing operations;

maintenance drawings, giving setting-up, adjustment and servicing of the articles and their parts;

patent claim drawings, relating to inventions and time-and-labour-saving proposals.

This standard subdivides drawings into six groups according to their contents:

(1) *detail drawings*, depicting individual parts and giving all information necessary for their manufacture and inspection;

(2) *assembly drawings*, showing assembled products, units and subassemblies, and giving all necessary information for their assembly and inspection;

(3) *general view drawings*, showing products, units and subassemblies, and giving their main characteristics;

(4) *outline drawings*, giving the outlines of each product or its components, together with overall, erection and fitting dimensions;

(5) *erection drawings*, showing an outline of the product or its component parts and containing all the data and information necessary for erecting the product (unit, etc.) in its correct place;

(6) *tabular drawings*, containing data for the manufacture and application of parts, units, subassemblies and products of one type.

All drawings are again subdivided into various groups depending on the stage of designing and the volume (type) of production.

This same standard also subdivides drawings of basic production into design drawings and working drawings.

Design drawings, in turn, are classified as *sketches* (which give only a general idea of the arrangement, dimensions and principle of operation of the product), and *engineering design drawings* (consisting, usually, of general views and assembly drawings, executed so that working drawings can be made from them).

Working drawings, according to which the production processes are conducted, are subdivided into:

lot or mass production drawings;

piece production drawings;

maintenance drawings.

All the above-mentioned drawings consist of a representation of a given product or of a unit, subassembly or component, of various inscriptions, dimensions, and conventional symbols.

Regardless of their type, purpose and contents, all engineering drawings are executed and completed according to definite rules specified by State Standards. These rules simplify drafting operations, ensure maximum clarity of drawing and facilitate their reading.

The rules embrace the following points in engineering drawings: size of drawing paper; scales; letter symbols; views, sections and revolved sections; lettering and figur-

ing; shading sections and revolved sections; lines; specification of maximum deviations and tolerances; methods of dimensioning; drawing and designation of threads; conventional symbols for gearings and chain drives; springs; rivets; bolts and bolt and rivet holes; conventional symbols for gearing diagrams; methods of showing position numbers and marking of the components of products; the inscription of surface finish symbols and finishing and heat treatment specifications.

The basic rules for making a drawing, which must be known in order to read a shop drawing, are as follows:

Drawing lines. Seven standard types of lines are used in drawings:

1. continuous main line
2. continuous line, light
3. continuous wavy line
4. broken line, light
5. broken line, heavy
6. dash-and-dot line, light
7. dash-and-dot line, heavy

Continuous main lines are used for drawing the visible outlines of an object, visible transition lines, the outlines of removed sections and of sectional views *.

Light continuous lines are used for outlining superimposed sections, for dimension and projection lines, and for shading sections and revolved sections.

Continuous wavy lines are used for break lines and for separating lines between views and sections.

Light broken lines are used for indicating invisible outlines of an object, the internal diameters of outer threads, the external diameters of threads in holes, and the circumferences and generating lines of the roots of gear teeth.

Heavy broken lines show lines of sections.

Light dash-and-dot lines are used for drawing centre lines (axes of symmetry), and pitch circles.

Heavy dash-and-dot lines show the borders of surface zones with different heat treatment or finish, the outlines of mechanisms in their extreme or intermediate positions and other auxiliary outlines.

* For sections, revolved sections, breaks, etc., see below.

It should be noted that the thickness of the above-mentioned lines can vary on the drawings, which also assists in their interpretation. Depending on the complexity and size of a drawing, the thickness of the visible outline line (continuous main line) varies between 0.6 and 1.5 mm; the thicknesses of all the other lines have the following relationships to its thickness:

No.	Line	Thickness
1	Continuous main line	b
2	Continuous light line	$b/3$ or less
3	Continuous wavy line	$b/2$ or less
4	Light broken line	From $b/2$ to $b/3$
5	Heavy broken line	From b to $1.5b$
6	Dash-and-dot line, light	$b/3$ or less
7	Dash-and-dot line, heavy	From $b/2$ to $b/3$

An example of the application of all the types of lines enumerated above is shown in Fig. 7.

Scales (M). The proportion of the representation of an object on a drawing to its actual size is called the *scale* to which it is drawn; in the Soviet Union, scales are limited by a State Standard. The symbol M1 : 1 indicates that the object is shown on the drawing full size; the symbols M1 : 2; M1 : 2.5; M1 : 4; M1 : 5; M1 : 10; M1 : 15; M1 : 20; M1 : 25; M1 : 50; and M1 : 75 indicate the reduction in the size of the image relative to the actual dimensions (M1 : 2—to half size; M1 : 10—to one-tenth, and so on);

M2 : 1; M2.5 : 1; M5 : 1 and M10 : 1 show how many times the image in the drawing is larger than the natural size of the article (M2 : 1—twice as large, M5 : 1—five times as large, and so on).

The designer chooses an appropriate scale, and makes the drawing of the object larger or smaller, depending on its complexity and actual size.

Incomplete projections; sections and revolved sections. In addition to complete projections (views), the rules for which have been described above, certain conventions and simplifications are employed in making shop drawings;

in some cases they considerably reduce the time taken for the drawing, reduce its size, and so on.

For example, the projection of parts of considerable length and uniform shape (pipes, bars, rods, etc.) is *not drawn in full, but with a break.* In these cases the central part of the object is not shown (as if it was broken out), only its ends being shown, separated by a continuous wavy line (Fig. 8*a*). For the same reason, if an object is projected as a symmetrical figure, only one half need be drawn. In this case the axes of symmetry serve as the boundary line between the halves shown and not shown (Fig. 8*b*). If more than half of an object is shown, its boundary will be drawn as a continuous wavy line (Fig. 8*c*).

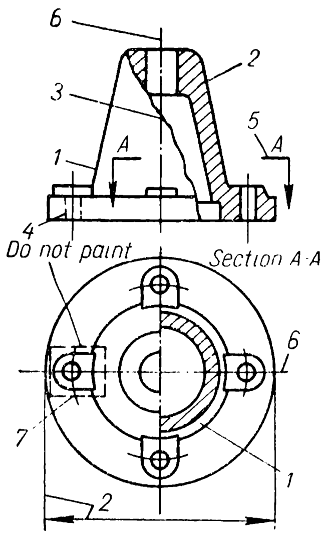

Fig. 7. Examples of drawing lines:

1—continuous main line, 2—continuous line, light, 3—continuous wavy line, 4—broken line, light, 5—broken line, heavy, 6—dash-and-dot line, light, 7—dash-and-dot line, heavy

Internal (hidden) outlines of parts may be shown by a broken line (Fig. 9*a*, main view); but often this is insufficient or impossible, because the drawing becomes overcrowded and difficult to read. In these cases sections and revolved sections are employed.

A *section* is a conventional representation in which a part of an object or machine is imagined to be cut or broken away so as to expose the interior; the interior view of the remaining part is drawn in full, i.e., everything that lies in and behind the cutting plane.

Places where the cutting plane has passed through the body of the object are shaded, and therefore differ sharply from the recesses in the cutting plane (Fig. 9*b*).

Depending on the direction of the cutting plane relative to the horizontal plane of projection sections are classified as:

horizontal sections, when the cutting plane is parallel to the horizontal plane of projection, for example, section *B-B*, Fig. 9*c*;

vertical sections, when the cutting plane is perpendicular to the horizontal plane of projection. Example: sections *A-A, C-C, D-D,* Fig. 9*c*;

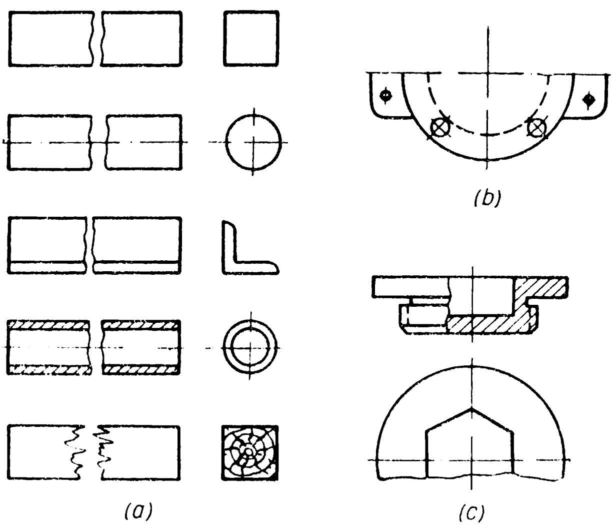

Fig. 8. Incomplete projections:
(*a*) with break, (*b*) half, (*c*) over half

inclined sections, when the cutting plane is at an angle to the horizontal plane of projection, greater or smaller than a right angle. Example: section *C-C*, Fig. 9*d*.

Depending on the number of cutting planes sections are classified as *simple* sections, formed by one cutting plane (Fig. 9*b*), and *complex* sections, formed by two or more cutting planes (section *B-B*, Fig. 9*c*).

Complex sections formed by several parallel cutting planes are called *stepped* sections (section *B-B*, Fig. 9*c*).

The direction of a cutting plane, in case the latter does not coincide with an axis of symmetry, is shown on the drawing by a line called a *section line* (shown by a broken line). Arrows are placed on the first and last dashes to show the direction of view. Identical letters are placed

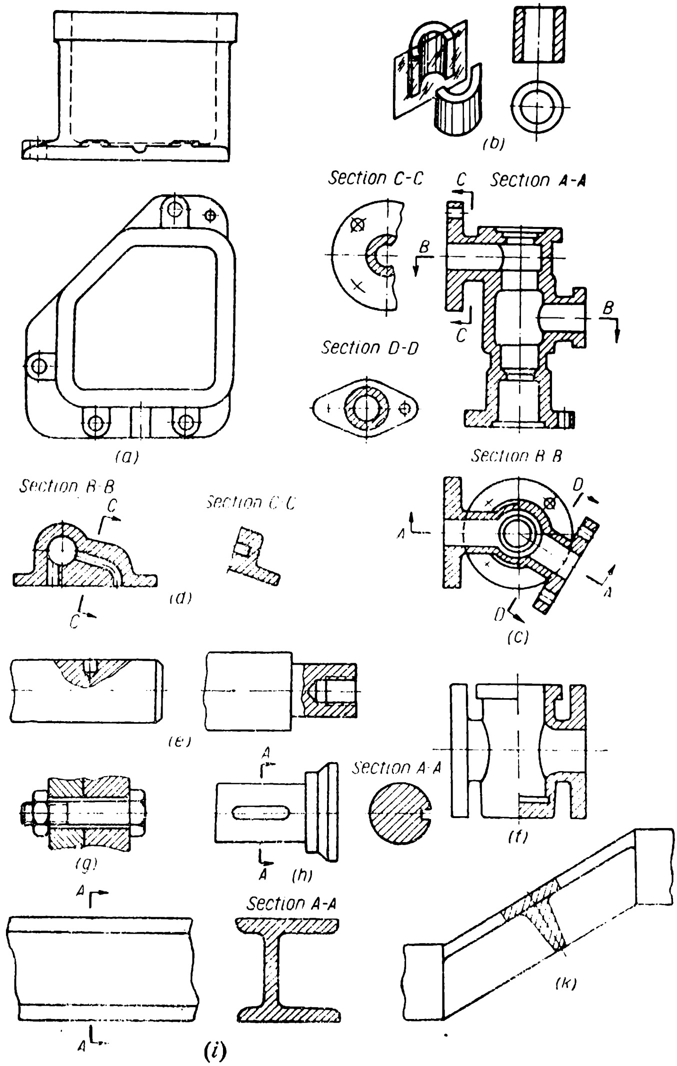

Fig. 9. Sections and revolved sections

at the beginning and end of the section line, and sometimes at the curves in the line; a corresponding inscription is put above the projection of the section (for example, *A-A, B-B,* etc.).

Sections may be *full* (Fig. 9*c*), or *local (partial)*, if they serve to clarify the construction of only a definite limited portion of an object; in this case the section is outlined by a continuous wavy line (Fig. 9*e*).

If the object or part of it is projected as a symmetrical figure, its half view and corresponding section may be combined as shown in Fig. 9*f*.

In cases where the section of parts such as screws, rivets, keys, solid shafts, spindles, connecting rods, handles, etc., are longitudinal, they are conventionally shown uncut and therefore not shaded (Fig. 9*g*). In cross sections (i.e., when the cutting plane is normal to their longitudinal axis) such objects are drawn according to the procedure given above.

Fixing nuts and washers are also shown uncut in longitudinal sections of assembly drawings. The same convention is applied in showing elements such as spokes of flywheels, pulleys, gears, thin rib-type walls, and so on, if the cutting plane is directed along their axis or their longer side.

A *revolved section* is a special type of section which shows only the location of the section, i.e., only that portion of an object which is located in the cutting plane itself, all parts lying behind the cutting plane not being shown. For example, Fig. 9*h*, shows the drawing of a shaft with a keyway, through which cutting plane *A-A* has passed. This section shows only the portion through which the cutting plane has passed, i.e., only the section that lies in the cutting plane. The portion of the shaft lying behind the cutting plane, i.e., the flange of the shaft, is not shown. If this were a simple section, the flange would also be shown.

Revolved sections can be *removed* (Fig. 9*j*) and *superimposed* (Fig. 9*k*). In the first case, the revolved section may be located anywhere in the drawing, in the second case—on the projection of the object itself. The outline of a removed section is drawn in a continuous main line, while outlines of superimposed sections are drawn in continuous thin lines. The outline of the projection on which the revolved section is superimposed is not broken.

Shading of sections and revolved sections. The shading for indicating metal in sections and revolved sections is specified in the corresponding State Standard of the U.S.S.R. and consists of thin parallel lines at an angle of 45° * to the centre line or the outline, whichever line may be taken as a base. The lines may incline either to the left or to the right, but for all sections and revolved sections of one and the same part the shading must be in the same direction.

The conventional symbols shown in Fig. 10*a* are used for shading sections and revolved sections of metals and other materials.

In drawings of stamped, rolled and other parts, long and narrow areas may be shaded, for metals as shown in Fig. 10*b*, and for nonmetals as shown in Fig. 10*c*.

Narrow areas of sections less than 2 mm in width are made in solid black, with gaps left between the adjacent sections instead of being shaded (see Fig. 10*d*).

Dimensions on drawings and how to read them. The only basis for judging the dimensions of an object is its dimensions expressed in figures written on a drawing irrespective of the scale.

In engineering drawings, linear dimensions are given in millimetres. If any other units of measurement are used, a note to this effect is made on the drawing, for example "dimensions in centimetres".

If the processing of a component includes coating, the dimensions shown on the drawing denote those before the coating is applied (except thread dimensions).

Dimensions are indicated by *dimension figures* and *dimension lines.* Dimension figures are placed above dimension lines (Fig. 11*a*) or in spaces between them (Fig. 11*b*). Arrowheads are drawn at the ends of dimension lines with their points touching the particular outline, extension, centre or other line to which they refer.

In the case of a broken projection, the dimension line must be unbroken, with arrowheads at each end (Fig. 11*c*). However, if a projection is only partially drawn (only up to the axis of symmetry or is broken off), the

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* If the direction of the shading lines coincides with that of the outline or of the centre lines, they may be drawn at angles of 30° or 60° instead of 45°.

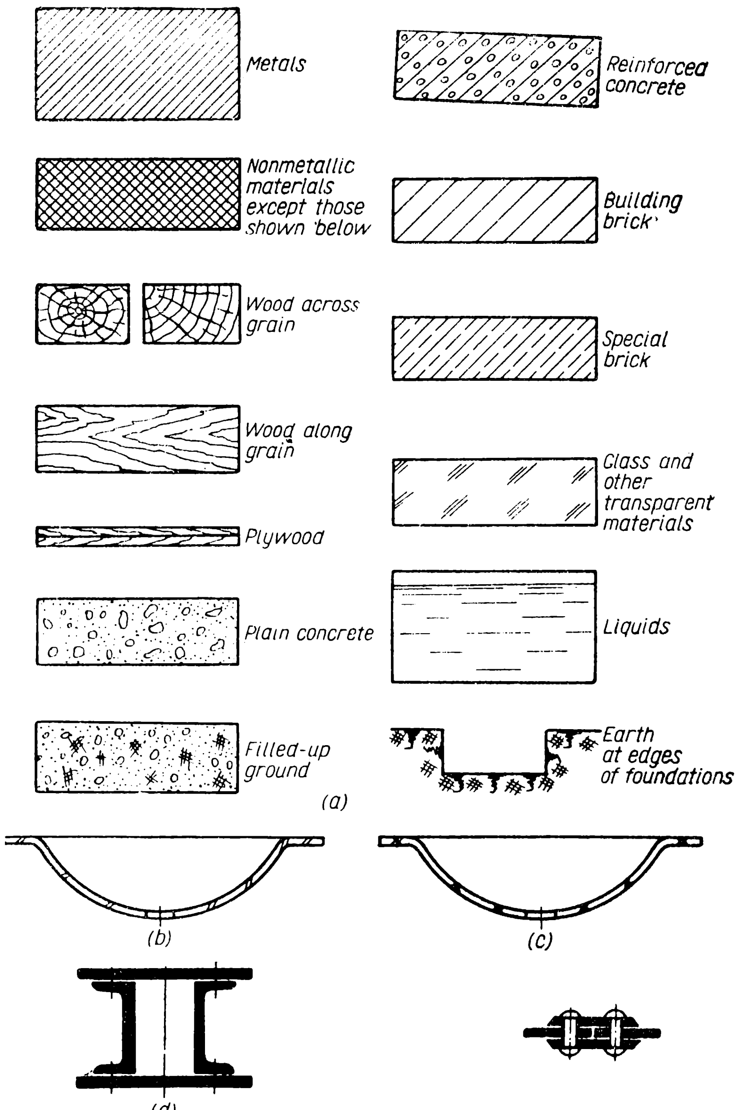
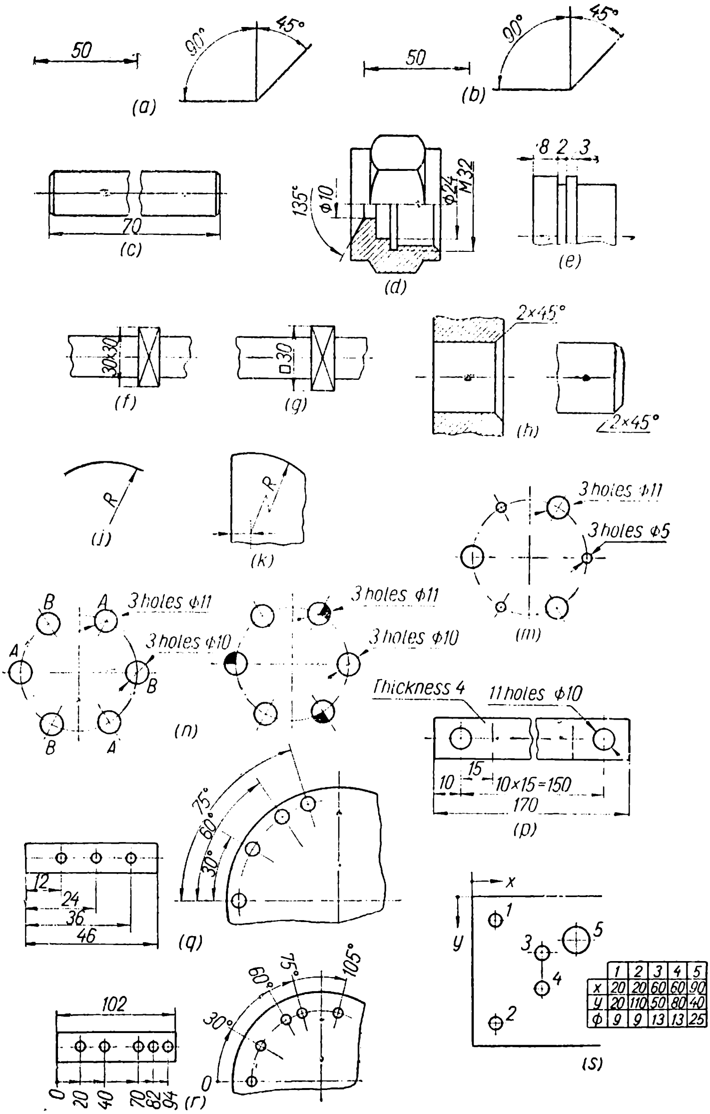


Fig. 10. Shading of sections and revolved sections



	1	2	3	4	5
x	20	20	60	60	90
y	20	110	50	80	40
Φ	9	9	13	13	25

Fig. 11. Dimensioning drawings

dimension line must be extended slightly beyond the axis (or line of break); in this case, it will have only one arrowhead (Fig. 11*d*).

If there is no room for arrowheads on consecutive dimension lines, they may be replaced by points or dashes on extension lines (Fig. 11*e*).

The symbol ∅ is always placed in front of a diameter dimension, and the symbol *R* in front of a radius dimension. The dimensions of a square (including a square hole) may be shown conventionally as 30×30, where 30 is the dimension of a side of the square (Fig. 11*f*), or they may be shown by the symbol □, placed in front of the dimension number of a side of the square, for example "□30" (Fig. 11*g*). The symbol ⌒ is always placed above the dimension number of the arc of a circle and the symbol ◺ in front of a dimension number showing a taper; the apex of this symbol must be pointed towards the taper apex. This symbol may be replaced by the inscription "taper" (for example, "taper 1 : 5").

The dimensions of 45° chamfers are determined by the length of the leg of the triangle formed by the chamfer, and are shown as in Fig. 11*h*. The dimensions of chamfers at other angles are indicated by two linear dimensions or one linear and one angular, according to the rules for all the other elements of the part.

If it is not necessary to show the centre of the arc of a circle, the radius dimension line is broken (Fig. 11*j*) However, if the location of the centre has to be shown (for example, for coordinating purposes), and the drawing is crowded or the radius is too long and the centre cannot be shown without violating the scale, the radius dimension line is shown with a break (Fig. 11*k*).

In drawing an object with several identical elements (for instance, holes, slots, chamfers, and so on), dimensions are indicated for only one such element with reference to their number (Fig. 11*m*). If there are several groups of elements on a drawing, differing in size, but similar in shape, similar elements are marked by letters or conventional symbols and dimensions are given only once for each type of element (Fig. 11*n*).

When several similar elements (for instance, holes) are located at equal distances from each other, one dimension may be given between adjacent elements and another

dimension between extreme elements; also, the number of spaces between the elements and the length of the space (Fig. 11*p*).

A number of adjacent dimensions may be taken from a common base (Fig. 11*q*) or a dimension line may be drawn from position *O* (Fig. 11*r*).

Dimensions may be also shown on a drawing by the method of coordinates (Fig. 11*s*), the dimension figures being given in a summary table.

Drawing and designation of threads. Threads are conventionally shown on drawings by two lines: by *continuous main line and by a broken line.* Continuous main lines are used for the outer diameter of a thread on a rod (bolts, screws, studs, etc.) and for the inner diameter in holes (nuts, tapped holes of various parts, etc.). The inner diameter of thread on a rod and the outer diameter of threads tapped in holes are drawn in broken lines (Fig. 12*a*).

If the thread in a hole is shown as invisible (not in section), both the outer and inner diameters are indicated by broken lines (Fig. 12*b*).

If it is necessary to give the profile of a thread (special, or nonstandard), it is drawn as shown in Fig. 12*c*.

In sections of a threaded connection in a hole, only that portion of the thread is shown which is not covered up by thread on the rod (Fig. 12*d*).

Threads are specified on a drawing by their type, outer diameter, pitch and precision class.

The *type (profile)* of a thread is shown conventionally on drawings. Basic metric threads are denoted by the letter M; fine metric threads—first, second, third, fourth and fifth by 1M, 2M, 3M, 4M, 5M; trapezoidal threads by the letters ТРАП; buttress threads by УП, and so on.

The *outer diameter* and *pitch* of a thread are indicated by figures with a multiplication sign (×) between them, placed to the right of the thread symbol. For instance, M10×1.5 indicates a basic metric thread with an outer diameter of 10 mm and a pitch of 1.5 mm; 2M48×2—second metric, diameter 48 mm and pitch 2 mm, and so on.

The *class of thread precision* is indicated after its pitch by the letters "кл" and the corresponding class number, for example M10 × 1.5 кл2.

If the thread size is not standard, the letters СП (special) are placed in front of the type symbol; for example, СП М60×2.5; СП ТРАП 50×5.

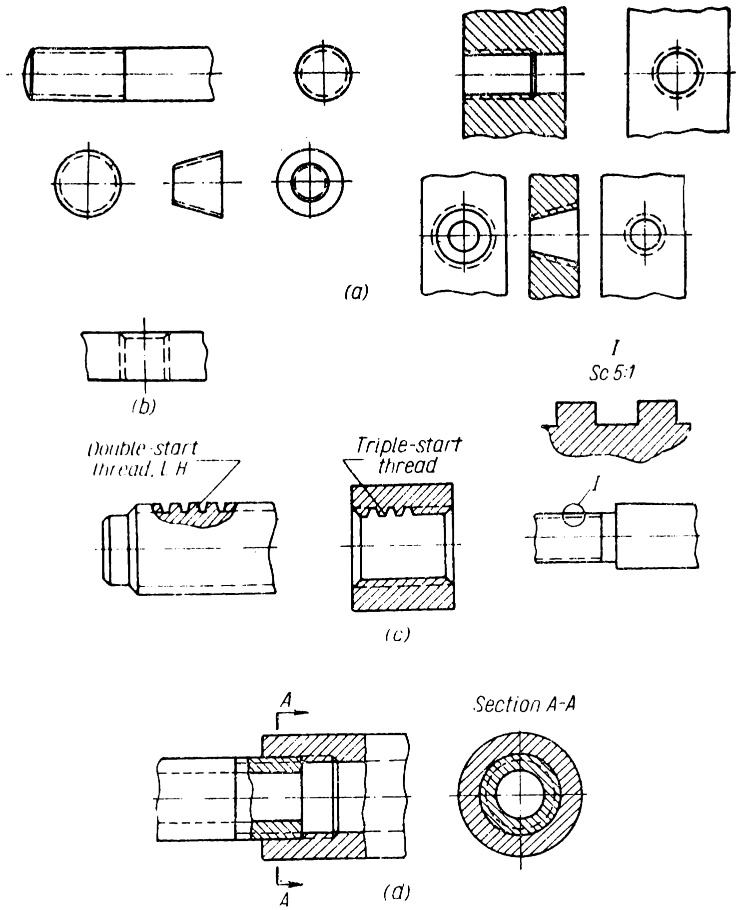


Fig. 12. Representing thread on drawings

A left-hand thread is specified by "лев"; for instance М24×2кл 2лев; ТРАП 22×2лев.

Surface finish designations on drawings. Surface finish is defined as the number of irregularities over very small portions of its surface (base lengths). Fourteen classes of

surface finish are established by the U.S.S.R. State Standard; classes 6-14 inclusive are further subdivided into categories which are denoted by the letters *a*, *b* and *c*. Each surface finish class and category corresponds to special requirements specified in this standard.

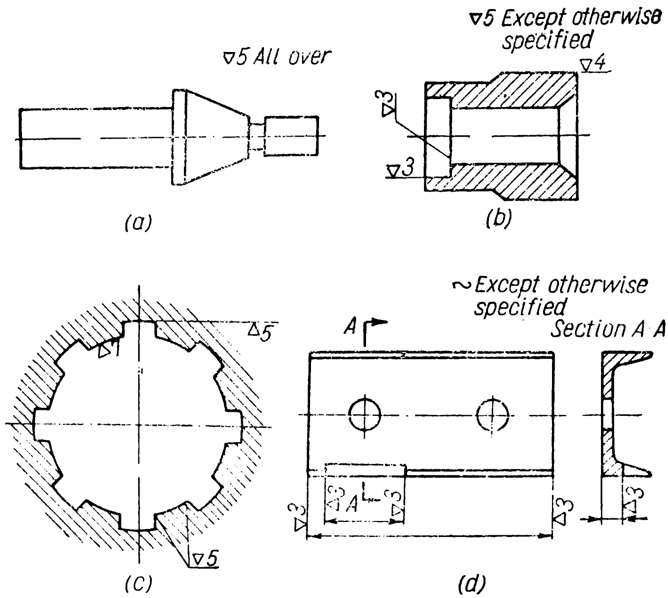


Fig. 13. Surface finish symbol on drawings

The conventional symbol for indicating surface finish on drawings is an equilateral triangle (∇) followed by the classification index, ∇7, or classification index plus the category symbol, ∇7*b*.

If the entire surface of a part is to have the same finish, a corresponding inscription is placed in the top right-hand part of a drawing (Fig. 13*a*). The words "all over" may be added to it (∇5 all over). In these cases the surface finish requirement is not inscribed on the drawing of the part itself. Should the surface of a part require more than one class of finishes, each section of the surface must bear an indication of the required finish.

When most of the surface is to have the same finish, but different finishes are required for separate elements, the conventional symbols may be placed as shown in Fig. 13*b*. In this case the surface finish of the major portion of the part's surface is not given. The finish of the same portion of a surface or of repeating surfaces (holes, teeth, etc.) is shown only once (Fig. 13*c*).

Surfaces of parts or blanks obtained by rolling, casting, stamping and forging, etc., and not requiring additional machining, are indicated by the symbol $\backsim$ (Fig. 13*d*).

Conventional representation of mechanisms and their elements in gearing diagrams. The operation of mechanisms and the interaction of their individual parts is illustrated by a simplified representation known as *gearing diagrams*. The mechanism and its elements are shown conventionally, by means of generally accepted symbols according to the corresponding State Standard of the U.S.S.R. The gearing diagrams of vertical drilling machines, shown in Figs. 57 and 64 are drawn in accordance with this standard.

Appendix 1 gives some of the conventional symbols for gearing diagrams according to Soviet Standards.

It should be noted that the rules for executing engineering drawings are not given in full, but only in so far as they concern drilling machine operators.

4. The Sequence of Reading Drawings

In order to read drawings correctly, the rules for making them should be learnt thoroughly and then used for practice studying and reading drawings.

Simple drawings should be tackled first, and then more complicated ones. A definite sequence must be followed, as otherwise some of its elements may be omitted which will, in turn, lead to errors in machining.

There is no established order of reading drawings, but the following sequence based on many years of experience can be recommended. By this method, even the most complicated drawings can be read quickly and correctly.

The first step is to read the main inscription located in the title block in the lower right-hand corner of the drawing. The title block carries the following informa-

tion: the part name and number; the scale to which it is drawn; the material from which it is to be made. After this, we ascertain the projections in which the part is drawn, and which is the main view. After this (applying the rules given above), the general shape and separate elements of the part must be understood.

The better the rules for locating projections on a drawing are studied and the use of the various types of lines, drawing of sections and revolved sections, etc., are grasped, the quicker and better will the shape of the whole part and each of its elements be understood. Remember that all views of the part must be examined simultaneously. This means that in examining any element it is essential to find and understand how it is shown in all projections, by using the methods for locating points described above.

When the shape of a part is clearly understood, its dimensions must be read, making sure which dimension applies to which element in all views.

If tolerances are given next to nominal dimensions their upper and lower limits must be calculated from the table of tolerances, and the accuracy class of the part must be determined. *

Remember that dimensions not given on a drawing cannot be found by direct measurement on the drawing. These dimensions must be obtained by calculation, even if the drawing is made to a scale of 1 : 1 (full size).

After all the dimensions have been determined, the surface finish marks must be examined, and then the engineering requirements read and studied, i.e., all the requirements applying to the part, as given on the drawing.

This is how drawings should be read.

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* For tolerances, fits and accuracy classes see Chapter IV.

Chapter IV

TOLERANCES AND FITS

1. The Principle of Interchangeability

In modern mass and large-lot production, entailing the manufacture of various articles in large quantities and at high speed, it is of vital importance that during the assembly of an article, each part occupies its intended place exactly, without any additional machining or hand-fitting operations. It is equally important that during repairs, any part of the article can be replaced by a new part without further fitting.

Parts which satisfy these requirements are called *interchangeable* parts. Interchangeability makes possible the specialization of production and cooperation of manufacturing plants. This means that various components of the same article can be manufactured in mass quantities simultaneously in several works. This simplifies assembly procedure, considerably reduces the cost of production and tool consumption, and ensures the required assembly speed on conveyor lines.

Interchangeability may be *complete* or *partial* (limited). In the first case any similar part from any given lot can be mounted during assembly without selection, adjustment or fitting; in the second case, partial or group selection of parts is required, but no additional machining will be necessary.

It follows from the above that, to achieve interchangeability of parts, they must be produced with identical dimensions. In practice, however, this is impossible. Even if several parts are made by one worker under similar conditions (same material, machine tool, tools, etc.), the dimensions of each part will differ slightly from the specified dimensions due to unavoidable errors in setting up the part, in measuring it, and as a result of tool wear.

It is even less likely that a large number of identical parts can be made by different workers, on different machine tools and in different works.

In order to obtain interchangeable parts and units (in spite of this apparent contradiction) it is necessary to determine, in advance, permissible deviations from the specified dimensions of manufactured parts.

The permissible deviations from the calculated dimensions may be different in each individual case and will depend on the specification of the part, its size, engineering requirements, etc.

2. Tolerances

In order to obtain interchangeable parts, it is necessary to satisfy various conditions stipulated by a system of tolerances and fits. This system defines permissible deviations, depending on the nature of the association (fit) of the parts and the required degree (grade) of accuracy of their mating.

The basic definitions and terms of the system are:

The mating dimension obtained by calculation or selected from design considerations, is called the *nominal size*. The nominal sizes of two mating surfaces of a part will always be the same. In calculations, nominal sizes are rounded off to nearest preferred basic size given in the corresponding State Standard of the U.S.S.R.

Mating surfaces of parts entering one another are distinguished as *enveloping* and *enveloped*. For example, in the assembly of a shaft and a bushing, the surface of the bushing hole will be the enveloping surface, and the shaft surface will be the enveloped surface. Correspondingly, the hole size is an *enveloping dimension*; that of the shaft—the *enveloped dimension*.

The dimension actually obtained as a result of machining a part and directly measured, is called the *actual size*. Due to inevitable errors during machining, the actual size always differs somewhat from the nominal.

The maximum and minimum dimensions between which the actual size may vary, are called the *upper and lower limits of size*.

The difference between the upper limit and the nominal size is called the *upper deviation*, and that between the

lower limit and the same nominal size is called the *lower deviation*. The difference between actual and nominal sizes is called the *actual deviation*.

The *tolerance* of a size is the difference between the maximum and minimum limits. It indicates the magnitude of permissible variations in the accuracy of machining a correctly made part.

Here is an example illustrating the above definitions: let us assume that the designer has calculated one of the basic dimensions of a part as 30 mm (nominal size), and that he has specified the maximum possible deviation from this size as 30.2 mm (its upper limit), and a minimum deviation from this size as 29.9 mm (its lower limit). The tolerance in this case will be 0.3 mm (30.2 — 29.9=0.3 mm). In this case, what will be the upper and lower deviations? The upper deviation will be 0.2 mm (30.2 — 30.0=0.2 mm), and the lower deviation will be —0.1 mm (29.9 — 30.0= = —0.1 mm).

According to the U.S.S.R. State Standard, drawings do not indicate the limits of size but show nominal sizes and the corresponding upper and lower deviations, i.e., in our example the drawing will carry not 30.2 and 29.9, but $30^{+0.2}_{-0.1}$, where +0.2 is the upper deviation from the nominal size; and —0.1 is the lower deviation *.

Thus, to calculate the limits of size from the nominal size and deviations given in a drawing, the deviation, depending on the preceding sign (plus or minus), must be added to or subtracted from the nominal size. In the given case, by adding the upper deviation (+0.2) to the nominal size (30), the maximum limit (30.2) is obtained; by subtracting the lower deviation (—0.1) from the nominal size, the minimum limit (29.9) is obtained.

But the maximum limit is not always higher, and the minimum limit is not always lower, than the nominal size. Quite often both limits are higher or, conversely, lower than the nominal size. This may occur when both limits have the same sign. For example, if for a nominal size of 25 mm, the upper deviation is +0.2, and the lower deviation is +0.1, the drawing will give the dimension as $25^{+0.2}_{+0.1}$. In this case the maximum limit will be 25.2 mm

* On drawings, deviations may also be indicated by conventional symbols (see p. 81).

(25+0.2=25.2 mm), and the minimum will be 25.1 mm (25+0.1=25.1 mm). Thus both limits are larger than the nominal; the tolerance is 0.1 mm.

Let us take another example: $25^{-0.1}_{-0.2}$; here the maximum limit is 24.9 mm (25—0.1=24.9 mm), and the minimum is 24.8 mm (25—0.2=24.8 mm), i. e., both limits are less than the nominal size; the tolerance is 0.1 mm as before.

The above examples show that the size 25 mm is obtained by calculation, and design considerations stipulate that the actual size of the finished parts be either above or below 25 mm.

A nominal size with limits may be also shown on a drawing as 35 ± 0.1. This means that the lower and upper deviations are numerically equal and, in order to avoid writing the same figure (0.1) twice, it is shown only once with the symbol $\pm$ in front. If one of the deviations is zero, it is not shown; for example $25^{+0.1}$ or $25_{-0.1}$. This means that, in the first case, the lower deviation is zero and the minimum limit is the same as the nominal; in the second case the upper deviation is zero and the maximum limit is the same as the nominal size.

The system of tolerances distinguishes two types of associations, or fits, as they are called, of two mating parts, *clearance* and *interference fits.*

For two mating parts to move freely in relation to each other during their operation as, for example, a shaft designed to rotate in, or slide along, a hole, the enveloping dimension (or hole diameter) must be larger than the enveloped dimension (or shaft diameter). The positive difference between the diameters of the hole and the shaft is called the *clearance.*

Sometimes, however, mating parts are not intended to move in relation to each other, i.e., they must remain absolutely fixed, as in the case of a pulley designed not to slide along or rotate on a shaft; in this case, their dimensions before assembly must be such that the shaft diameter is larger than the hole diameter. Here, the difference between the diameters of the shaft and hole is negative and is called the *interference.*

Since the actual dimensions of shaft and hole diameters may vary (within tolerance limits), the amount of clearance and interference may also vary.

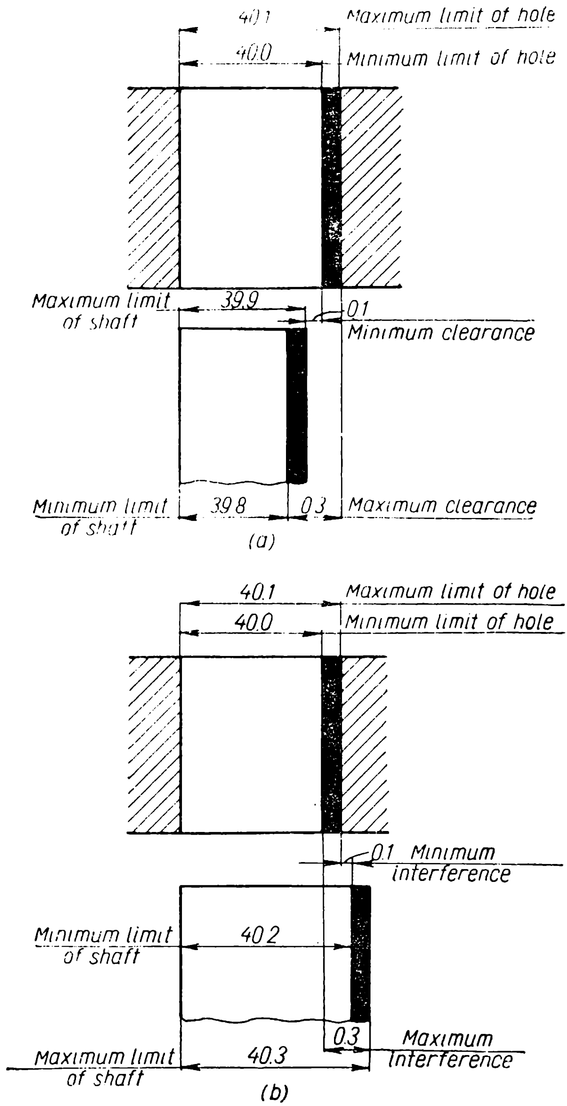

Fig. 14. Graphic representation of clearances and interferences

Therefore, the system of tolerances defines maximum and minimum clearance and interference.

The *maximum clearance* is equal to the difference between the maximum limit of the hole and the minimum limit of the shaft.

The *minimum clearance* is equal to the difference between the minimum limit of the hole and the maximum limit of the shaft.

The *maximum interference* is equal to the difference between the maximum limit of the shaft and the minimum limit of the hole.

The *minimum interference* is equal to the difference between the minimum limit of the shaft and the maximum limit of the hole.

Graphic illustrations of clearances and interferences are given in Fig. 14 *a* and *b*.

3. Fits

The type of association between mating parts is called a *fit*, and depends on the difference between the dimensions of the mated parts, i.e., on the presence of clearance or interference.

The State Standard of the U.S.S.R. establishes a definite list of fits, divided into three basic groups: clearance (movable) fits, interference (fixed) fits and transition fits.

Fits in which clearances are provided are called *movable* or *clearance* fits; if the fit has interference, it is called an *interference* fit. Movable fits may have clearances, and interference fits may have interferences of various magnitudes, depending on the difference between the diameters of the mating parts.

Fits with small degrees of interference or clearance are called *transition* fits.

Each fit in any group has a definite name and symbol which, to a certain extent, define its nature.

A list of fits for nominal diameters between 1 and 500 mm, together with their symbols, are given in Table 2.

Clearance fits. The *slide fit* (S) is employed to mate parts with sufficient closeness to ensure the exact alignment of their axes. In operation, such parts are moved manually or by power at low speeds. This fit has the smallest clearances (from 0 to the sum of hole and shaft tol-

Table 2

Types of Fits for Nominal Diameters* from 1 to 500 mm

Group of fits	Designation of fits	Symbol
Clearance	Slide	S
	Easy slide	Se
	Running	R
	Slack running	Rs
	Loose running	Rl
Interference	Heavy drive	Dh
	1st heavy drive	Dh1
	2nd heavy drive	Dh2
	3rd heavy drive	Dh3
	Light drive	Dl
	Shrink	Sh
Transition	Force	F
	Tight	T
	Wringing	W
	Push	P

* Here, and throughout this book, we have used as fit symbols the letters which correspond to the English names of the fits. It must be understood, however, that in Soviet engineering drawings, fits are specified by Russian capital letters which correspond, in the same manner, to the Russian names of the fits. These symbols are:

Shrink (Sh)	Гр	Push (P)	П
Heavy drive (Dh)	Пр	Slide (S)	С
Light drive (Dl)	Пл	Easy slide (Se)	Д
Force (F)	Г	Running (R)	Х
Tight (T)	Т	Slack running (Rs)	Л
Wringing (W)	Н	Loose running (Rl)	Ш

English names, given here to the fits in the U. S. S. R. standard, have been selected to broadly characterize their properties. It is not to be inferred that they coincide in tolerances with fits of the same name employed in England or the United States.

erances), as, for example, in drill spindles, jaw clutches, machine-tool change gears, milling cutters on arbours, etc.

The *easy slide fit* (Se) is used to mate parts designed for moving freely in relation to each other with a slight clearance at slow speeds. Such parts include dividing head spindles and various instruments, slip jig bushings, etc.

The *running fit* (R) is used for mating parts and units designed to rotate at moderate speeds, e.g., lathe spindles, crank and cam shafts fitted in bearings and bushings, tractor and automobile transmission gears, etc.

The *slack running fit* (Rs) is used for shafts rotating at high speeds with comparatively light loads on their bearings, e.g., electric motor shafts, cylindrical grinding machine drive shafts, etc. Here, the minimum clearance is twice that of the running fit.

The *loose running fit* (Rl) has the largest clearances and allows a free movement of parts in relation to each other. It is used for shafts rotating in bearings at very high speeds (turbogenerator shafts, piston rings in grooves, etc.).

Interference fits. *Heavy drive fits* (Dh, Dh1, Dh2, Dh3) are employed when the mating parts are required to be rigidly held together by interference alone (without additional locking by keys, pins, set screws, etc.). Heavy drive fit Dh1, for example, is used for press-fitting bushes into gears and pulleys, and driving valve seats into places; heavy drive fits Dh, Dh2 and Dh3 are used for mating components subject to heavy impact loads, e.g., for fitting the toothed rims on the hubs of worm and other gears, crank pins into disks, etc.

The *light drive fit* (Dl) is applied for similar purposes as the heavy drive fit Dh1, but it has a slightly less interference.

Parts designed with heavy drive fits are assembled in presses of various capacity.

Shrink fits (Sh) are employed for making fixed permanent joints. They differ from drive fits in that they ensure rigid, inseparable associations by merely heating the part with the hole; this part is then slipped over the part to which it is to be mated and allowed to cool (or the part to be fitted is cooled and passed through the hole in its mating part). On cooling, the heated part shrinks over the cold mating part.

The shrinkage of the metal is accompanied by considerable stresses, and for this reason shrink fits are mainly employed for steel parts

Transition fits. The *force fit* (F) is employed when a close, rigid fit of mating parts is desired, e.g., for fitting bushes in solid bearings, coupling sleeves on shafts, etc.

But to prevent the movement of such parts during their operation, they must be secured by keys, pins, or locks.

Tight fits (T) are intended for ensuring close fits between parts designed to maintain their relative positions during operation. Their assembly and disassembly require considerable force. Tight fits are employed for mounting pulleys, gears, inner ball bearing rings, etc., on shafts.

Wringing fits (W) are used for ensuring close fits between parts to be assembled and disassembled by tapping lightly with a lead hammer.

Push fits (P) are used for ensuring rigid fits between parts which can be assembled and disassembled only by tapping lightly with a mallet.

4. Accuracy Grades

The precision with which a part is to be manufactured will depend on the requirements made to the mechanism, unit or machine to which it belongs. Thus, for instance, parts for measuring instruments are made with greater precision than parts for lathes which, in turn, are made with greater precision than parts for agricultural machinery. In other words, one and the same fit may be achieved with different degrees of accuracy.

In the system of tolerances for the engineering industries, the U.S.S.R. State Standard specifies 10 grades of accuracy (for dimensions from 1 to 500 mm). The first five grades—1, 2, 2a, 3, 3a—are the most precise and have the narrowest tolerances; the two following grades—4 and 5—are less precise; the other three—7, 8 and 9 (class 6 is omitted in the system), have the widest tolerances and are intended for nonmating dimensions.

Table 3 gives information on the different accuracy grades and gives methods for machining parts to obtain the required grade of accuracy and fit.

The accuracy grade of any given fit is specified on drawings by a subindex following the fit symbol. For instance, F_1 denotes a 1st grade force fit; R_4—a 4th grade running fit; $Dh2_3$—a 3rd grade 2nd heavy drive fit, and so on. Only second accuracy grade fits have no subindex; for instance, Dh indicates a heavy drive fit of the second grade of accuracy; T—a tight fit of the same grade, and

Table 3

Methods of Machining Parts Depending on Accuracy Grades

Accuracy grade	Application	Machining methods		Fits	Remarks
		holes	shafts		
1	Critical associations of extra-high precision (antifriction bearings, ball and roller bearings, parts of precision measuring machines and instruments)	Sizing and lapping small holes, honing, precision boring, lapping large holes	Precision grinding, lapping, polishing	1st heavy drive 2nd heavy drive Force, tight, push, wringing, slide and easy slide	Highest grade used in the engineering industries
2	Machines and mechanisms operating at high speeds: parts of machine tools, tractor, automobile and aircraft engines, electrical machines, etc.	Finish reaming, precision finish grinding, pull and push broaching, and honing	Precision finish grinding, finish turning	All fits except 1st and 2nd heavy drive fits	Most widely used in the engineering industries
2a	Ditto.	Reaming, broaching, grinding	Finish grinding and turning	Force, tight, wringing, push, and slide	

3	Parts of automobiles and tractors, agricultural and textile machinery, etc., not subject to heavy duty	Boring with finishing tool, reaming, grinding	Finish turning	[illegible] and heavy drives, slide, running and loose running	
3a	Parts of automobiles, tractors, agricultural, textile machines, etc., not subject to heavy duty	Boring with single-point tool, rough reaming, grinding	Finish turning of large diameter shafts and grinding of small diameters	Slide	
4	Agricultural machinery, locomotive and car building industries, mating of stamped parts, etc.	Precision drilling by one drill in jig, two drills, core drilling	Finish turning	Heavy drive, slide, running, loose running, slack running	
5	Ditto	Ditto	Ditto	Slide and running	
7 8 9	Not applied for mating parts. Applied only for making parts with permissible coarse deviations from nominal dimensions	Hot closed-die forging, sand casting	Smith and drop forging, rolling, roughing, casting, cutting off	None	Tolerances for free (nonmating) dimensions are selected from these grades

so on. But fits of accuracy grade 2a, as fits of other grades, are denoted by a symbol and a figure index; for instance T_{2a} denotes a tight fit of the 2a grade.

5. Hole Basis and Shaft Basis Systems of Fits

Different fits can be obtained in two ways for the same nominal size of two mating parts.

In the first case, the limits of the hole will remain constant, and any fit for this hole will be obtained by correspondingly varying the limits of the mating shaft. This system is called the *hole basis system* and is denoted by the letter A. The distinguishing feature of this system is that the lower deviation of the hole is always zero (i.e., the minimum limit is equal to the nominal size), and the upper deviation is always positive. In other words, the tolerances in this system increase the dimensions of the hole or, as it is usually said, are directed "into the body" of the part.

In the second case, the limits of the shaft remain constant, and the different fits are obtained by correspondingly varying the limits of the mating shaft. This system is called the *shaft basis system* and is denoted by the letter B. The distinguishing feature of this system is that the upper deviation of the shaft is always zero (i.e., its maximum limit is equal to its nominal size), and the lower deviation of the shaft is always negative (tolerances in this system are again directed "into the body" of the mating part, but they reduce the diameter of the shaft).

Thus, in each system, the size of one of the mating elements is basic (that of the hole in the hole basis system; that of the shaft in the shaft basis system), while the other size is the mating dimension (the shaft dimension in the hole basis system; the hole dimension in the shaft basis system).

As may be seen from Fig. 15, which gives a schematic diagram of the 2nd accuracy grade fits, any required fit can be obtained irrespective of any variation in the shaft dimension (by the hole basis system) or in the hole dimension (by the shaft basis system). In both cases the results will be the same.

Each system has its advantages and disadvantages.

The hole basis system requires fewer tools—drills and reamers—to make the holes. In addition, shafts of various diameters are considerably easier to machine, and with greater precision, than holes. The advantages of this system are quite considerable and for this reason most enterprises in the Soviet Union use the hole basis system.

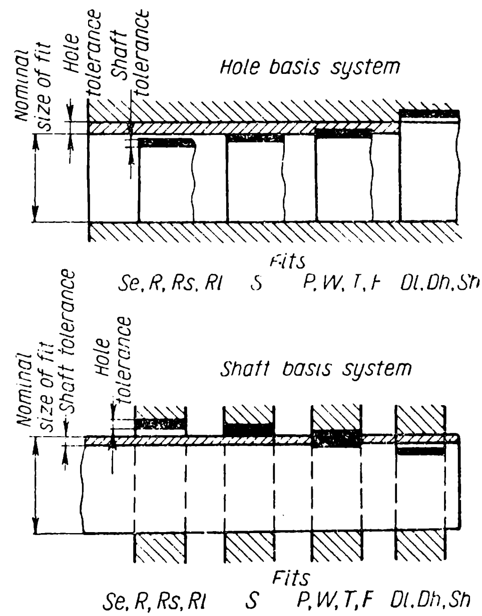

Fig. 15. Graphic representation of hole and shaft basis systems

However, if one long shaft has to carry several different parts, for example, a pulley, a coupling and a bearing with different fits, the shaft basis system is to be preferred. Using the hole basis system in this case, the shaft would have to be made with steps to different tolerances. This is unprofitable from the production point of view.

6. Tolerance Tables and Examples of Use

Special tables are available for each of the tolerance systems described above (the hole basis system and the shaft basis system), compiled for all grades of accuracy.

They list the permissible upper and lower deviations from the nominal diameters for all fits within the given grade of accuracy. They cover nominal diameters from 1 to 500 mm, divided into groups (from 1 to 3 mm inclusive, over 3 to 6 mm, over 6 to 10 mm, and so on), the tolerances for each group being equal.

Since permissible deviations from nominal sizes are usually very small values, the writing of unnecessary zeros is avoided by giving deviations in the tables as microns (abbreviated μ), thousandths of a millimetre. The first column of each table gives the nominal diameters (in mm); the second—hole or shaft deviations (depending on the system chosen), and the others—the different fits, with corresponding deviations for each group of nominal dimensions.

Table 4

Tolerances and Fits for 3rd Accuracy Grade in the Hole Basis System

Nominal diameters, mm	Hole deviation, A, in microns		Shaft deviation, Fits, in microns: slide, S_3		running, R_3		loose running, Rl_3	
	lower	upper	upper	lower	upper	lower	upper	lower
From 1 to 3 inclusive . . .	0	+20	0	—20	—7	—32	—17	—50
Over 3 to 6	0	+25	0	—25	—11	—44	—25	—65
„ 6 „ 10	0	+30	0	—30	—15	—55	—35	—85
„ 10 „ 18	0	+35	0	—35	—20	—70	—45	—105
„ 18 „ 30	0	+45	0	—45	—25	—85	—60	—130
„ 30 „ 50	0	+50	0	—50	—32	—100	—75	—160
„ 50 „ 80	0	+60	0	—60	—40	—120	—95	—195
„ 80 „ 120	0	+70	0	—70	—50	—140	—120	—235
„ 120 „ 180	0	+80	0	—80	—60	—165	—150	—285
„ 180 „ 260	0	+90	0	—90	—75	—195	—180	—330
„ 260 „ 360	0	+100	0	—100	—90	—225	—210	—380
„ 360 „ 500	0	+120	0	—120	—105	—255	—250	—440

As an example, let us determine from Table 4 the permissible limits for a hole and a shaft with a nominal diameter of 60 mm for a running fit of the 3rd accuracy grade.

The nominal diameter of 60 mm is found in the column headed "Nominal diameters" in the group of dimensions "over 50 to 80".

The corresponding deviations for the hole are found in the "Hole deviation" column, the lower deviation being zero, and the upper $+60\ \mu$. Therefore, the maximum limit of the hole will be 60.06 mm ($60+0.06=60.06$), and the minimum will be 60 mm, since the lower deviation is zero. Shaft deviations are found in the "running R_3" column of fits; the upper deviation is $-40\ \mu$, and the lower $-120\ \mu$. Thus, the maximum limit of the shaft will be 59.960 mm ($60-0.040=59.960$), and the minimum limit will be 59.880 mm ($60-0.120=59.880$).

7. Tolerance Symbols on Drawings

Tolerances are given on drawings as limit deviations from nominal sizes and are placed immediately after the latter. Tolerances may be indicated by symbols ($20X_3$) or numerical values ($20^{-0.025}_{-0.085}$). Numerical values of deviations may also be shown together with symbols:

$$20X_3\left(^{-0.025}_{-0.085}\right).$$

If tolerances are given according to the hole basis system, the size and tolerance of the hole are conventionally shown as $20A_3$, and the shaft size and tolerance as $20X_3$. If tolerances are given according to the shaft basis system, the shaft size and tolerance are shown as $20B_3$, and hole size and tolerance as $20X_3$.

Tolerances, as a rule, are not given for nonmating (free) dimensions. Instead, a note is given on the drawing, for example "Tolerances for free dimensions to 7th grade of accuracy".

In conclusion, it must be noted that we have studied tolerances and fits for smooth cylindrical connections only, as they are the most widely used in machine building. But the fundamental conditions and rules examined here refer equally to other associations, such as threads, splines, etc.

Chapter V

FUNDAMENTALS OF THE MANUFACTURING PROCESS

1. The Manufacturing Process and its Elements

The *manufacturing process* is that part of the production process directly concerned with changing the dimensions, form or properties of the materials being worked. The combination of methods and procedures, based on scientific facts and experience and used to convert raw materials into finished products, is called the manufacturing process of a given production.

The manufacturing process is planned on the basis of drawing data. It determines: the order and method of machining workpieces; the equipment, jigs, fixtures and tools to be used, depending on the selected machining method; machining speeds and feeds; and means and methods of inspecting the quality of the finished products.

The production of each part involves a particular manufacturing process which, in turn, consists of a number of operations.

An *operation* is a complete stage in the manufacturing process of machining a part. It is performed at one workplace by one or several workers (team).

Depending on the number of parts per lot, their design, the level of technique and organization of production at a particular works, the operations may be *concentrated* (consolidated) or *differentiated* (broken down).

For example, in small-scale piece production the entire assembly of parts is often performed by a single worker at one workplace; it is planned and recorded as one operation. The same work in large-lot and mass production is broken down into a series of independent operations performed by different workers at different workplaces.

The amount of work entailed in an operation is of great importance. As a rule, the more work it entails, and

the more complex the operation, the lower the labour productivity and the greater the need for highly skilled workers. On the other hand, the greater the operation breakdown into simple operations, the higher the labour productivity and the lower the cost of machining the part. The breaking down of operations enables workers to adapt themselves better to performing simple, similar working processes and to use special jigs and fixtures.

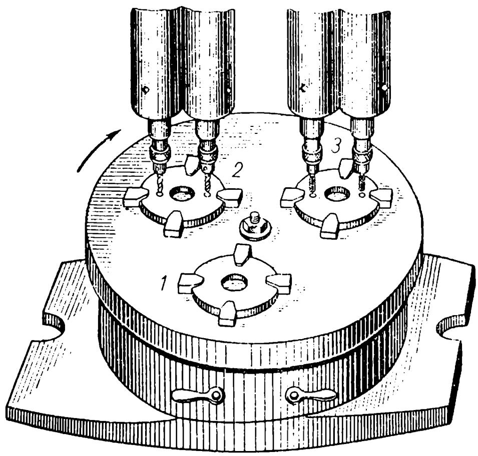

Fig. 16. Drilling holes on a three-station fixture

Each operation, in turn, can be subdivided into component parts, the number of which varies with the scope of the operation and methods of its execution. The basic components of an operation are: the station, setting, the operation element, the cut or pass, and the elementary handling operation.

By a *station* is understood each of the different positions of a workpiece relative to the cutting or machine tool. Fig. 16 gives an example of machining a workpiece in different stations. It shows a three-station rotary fixture for drilling and tapping holes.

The workpiece is clamped in place in the first station; after turning the fixture to the second station, the holes are drilled and, after the next turn, the threads are cut inside the hole (the holes are tapped).

A *setting* is that part of an operation performed during the period between the clamping of a workpiece on the machine or in a fixture, and its release. For example: the $2 \times 60°$ chamfers on the bushing shown in Fig. 17*a* are made in two settings: in the first setting, one end of the

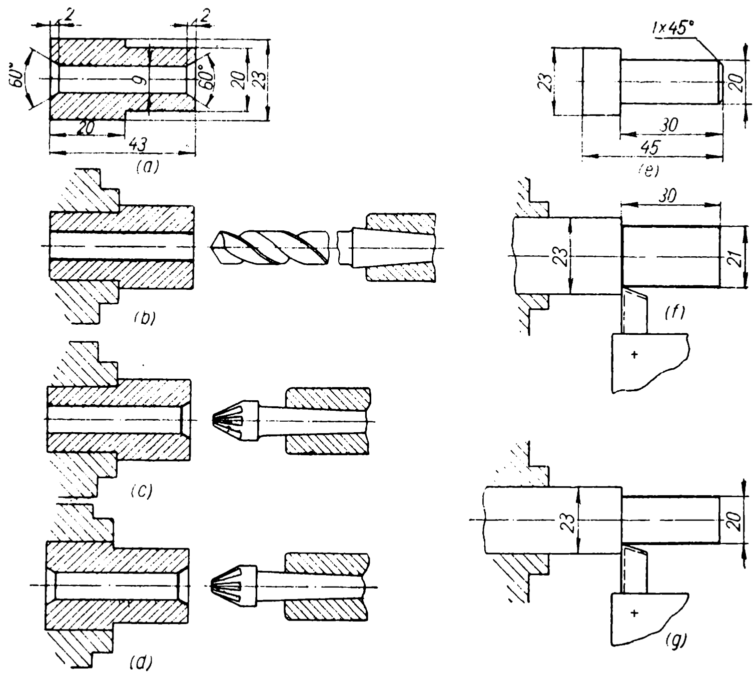

Fig. 17. Operation elements

hole is chamfered (Fig. 17*c*) after which the workpiece is released, repositioned, reclamped and its second end chamfered (Fig. 17*d*) in the second setting.

An *operation element* is that part of an operation which is performed on one or more surfaces of a workpiece without changing the tool setting and without changing the cutting speed or feed. The next operation element begins when any one of the above factors is changed, i.e., when a new surface is machined, when a new tool is used, or when different speeds or feeds are applied.

For instance, in Fig. 17*b*, drilling the 9 mm diameter hole in the bushing is the first operation element and is performed with a drill; the second operation element is cutting chamfers 2×60°, which is performed with a countersink (Fig. 17*c*).

The *pass*, or *cut*, is that part of an operation element that includes all the procedures required to remove one single layer of metal with the same tool, on the same surface and without changing the speeds, feeds and depth of cut. For example, for finish turning the shaft journal (Fig. 17*e*) from dia 23 mm to 20 mm, at least two cuts will be required; during the first (roughing) cut a 2 mm layer of metal is removed (Fig. 17*f*), and during the second (finishing) cut—a layer of metal 1 mm thick (Fig. 17*g*)*.

An *elementary handling operation* is a completed action by worker in performing an operation which is repeated with the machining of each new part. Such operations include: bringing the workpiece to the machine, clamping it on the machine, starting the machine, removing the machined work, putting it in a definite place, etc.

2. Process Sheets

The manufacturing process for the production of a part (or for assembling an article) is entered in a special document called the *process sheet*. The type of process sheet will depend on the type of production (piece, lot or mass production).

In piece production and sometimes small-lot production, process sheets are drawn up as *route*, or master, process sheets, in which only the sequence of operations is listed.

For large-lot and mass production, however, process sheets are compiled for each operation on each part. Such process sheets are called *operation sheets* and give detailed information required for machining and inspecting each part in each operation. Thus, for example, machining operation sheets contain:

(1) the name of the article and the part name; the

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* Fig. 17 does not give all the operation elements required to obtain the parts shown (Fig. 17*a* and *e*); only those elements of the operations illustrating the setting, operation element and cut are shown.

number of the drawing of the part, or article of which the part is a component; the name of the operation;

(2) the material of which the part is made; the type and dimensions of the blank; the quantity of parts per lot;

(3) the number of each operation, setting, operation element; description of each setting and operation element;

(4) a sketch of the part, showing places to be machined, dimensions, tolerances and surface finish for each operation; sketches of operation elements showing dimensions for each element;

(5) the name, type, brief specifications and model of the machine tool; the number and name of each jig and fixture, cutting tool and measuring tool required for each operation element;

(6) cutting conditions (depths of cut, feeds, cutting speeds, rpm, number of cuts); the standard (piece) time per operation and the job category;

(7) instructions for checking (inspecting) individual elements of the part machined in the given operation; who is to be responsible for inspection (worker, foreman or inspector) and the tool or instrument to be used for such inspection.

The process sheet is the basic production document and its instructions are obligatory for all concerned in the production of a part (unit, article).

This does not mean, however, that the manufacturing process may not be changed. On the contrary, the production process should be improved to ensure a continuous increase in the productivity of labour, reduction of production costs and improvement of quality. Revisions of process sheets, however, may be made only by the process engineering department of the works. Therefore, unauthorized changes on the part of workers, foremen, etc., are prohibited.

An example of an operation sheet as used by one engineering works is given in Appendix 2.

Chapter VI

FUNDAMENTALS OF THE DRILLING PROCESS AND CUTTING FEEDS AND SPEEDS

1. Fundamentals of Metal-Cutting Theory

The essence of working metals by cutting consists in the removal of excess stock (machining allowance) from the surface of a blank or workpiece. In this process, the blank acquires the shape, dimensions and surface finish specified in the drawing.

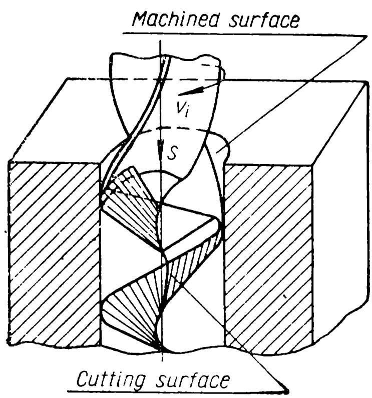

Fig. 18. Surfaces on the workpiece

Metals are machined by cutting tools on various metal-cutting machine tools: lathes, milling machines, planers, drilling machines, grinders and others.

Three kinds of surfaces are distinguished in the cutting process: the work surface, the machined surface and the cutting surface (Fig. 18).

The surface to be machined is called the *work surface.* The surface left by the cutting tool after machining (in drilling this is the cylindrical surface of a drilled hole)

is called the *machined surface*. The surface on the work that is generated by the cutting edge of the tool in the process of cutting is called the *cutting surface*.

The cutting process may involve two working motions of the cutting tool relative to the work being machined: rotation and feed.

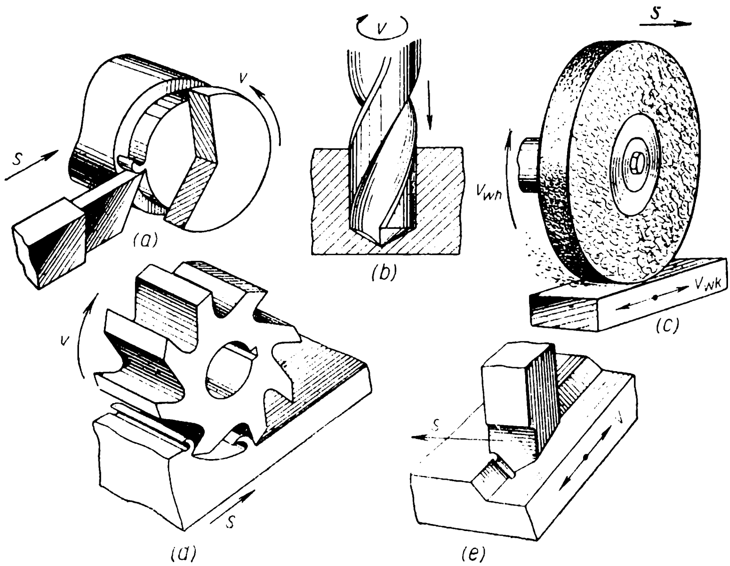

Fig. 19. Working motions during machining:
(*a*) turning, (*b*) drilling, (*c*) grinding, (*d*) milling, (*e*) planing

In some types of machining, the tool performs only one of these motions and the part performs the other (for example, on a lathe the part rotates and the tool is fed).

The working motions of different machine tools are shown in Fig. 19.

Elements of cutting during drilling. In the process of originating or enlarging holes with drilling machines a drill simultaneously performs rotating and feed motions. In doing so, the drill lips cut off thin layers of metal from the rigid workpiece to form chips which, curling and sliding along the helical flutes of the drill, escape from the hole being drilled. The more rapidly a drill rotates and the further it travels along its axis per revolution, the faster the drilling process.

The speed and diameter of the drill determine its cutting speed; and its axial travel per revolution determines the thickness of the cut chips.

The drill, in comparison with other cutting tools, operates under fairly difficult conditions; in drilling, the removal of chips and the delivery of lubricants and coolants to the tool present difficulties.

At the beginning of drilling, the face surfaces on the lips of the drill compress the adjoining particles of metal. Then, as the pressure developed by the drill increases and exceeds the cohesion between the particles of metal, the latter separate from the work surface in the form of chips. Chips are distinguished as: *continuous chips* (formed when machining steels) and *discontinuous chips* (formed when machining brittle metals such as cast iron, bronze, etc.).

The basic cutting elements during drilling are: the cutting speed and the depth of cut; the feed, the thickness and width of the undeformed chips (Fig. 20).

The *cutting speed* v is the distance travelled by the lips of the drill relative to the workpiece in unit time. The cutting speed is determined by the formula *

$$v = \frac{\pi Dn}{1{,}000}$$

where v is the cutting speed, m/min

D is the drill diameter, mm

n is the drill speed, rpm

π is a constant, equal to 3.14.

The cutting speed depends on the material being machined, the drill diameter and material, the drill geometry and the feed, depth of cut, and cutting fluid being used.

The *drilling feed* s is the distance of axial travel of the drill per revolution.

The rate of feed in drilling and enlarging holes depends on the required finish and accuracy, the machined material, the strength of the drill and the rigidity of the "machine tool-workpiece" complex.

The *depth of cut* t is the distance between the machined surface and the drill axis (i.e., it is equal to the drill

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* As the hole diameter is expressed in millimetres, and the cutting speed in metres, πD is divided by 1,000.

radius). The depth of cut is determined by the formula

$$t = \frac{D}{2}$$

where D is the drill diameter, mm
t is the depth of cut, mm.

The *thickness of the undeformed chip* a is measured in a direction perpendicular to the lip of the drill.

The *width of the undeformed chip* b is measured along the cutting edge and is equal to its length.

The *cross-sectional area of the undeformed chip* f removed by both lips of the drill is determined by the following formula:

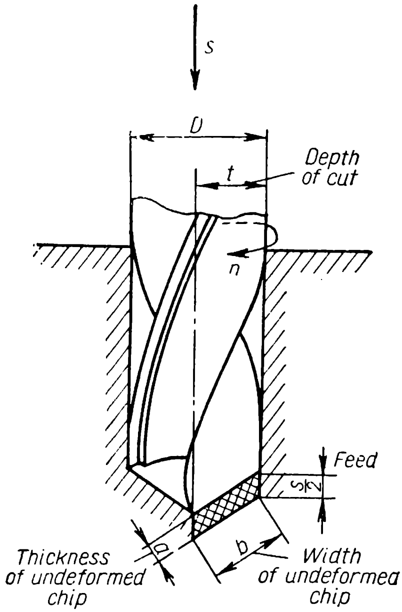


Fig. 20. Elements of cutting in drilling

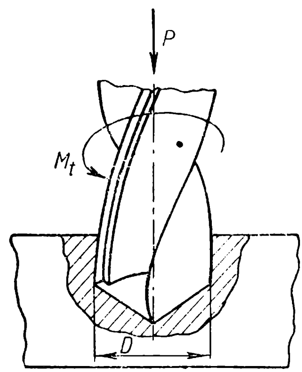


Fig. 21. Forces acting on a drill

$$f = st$$

where f is the cross-sectional area of the undeformed chip, sq mm
s is the feed, mm/rev
t is the depth of cut, mm.

Thus, the cross-sectional area of the undeformed chip increases with the drill diameter and, for a given drill, with the feed.

During the drilling of holes the machined material offers resistance to cutting and to the removal of chips. In order to effect the cutting process, a feed force P, exceeding the strength of the material being cut, must be applied to the cutting tool by means of the drilling machine feed drive, and a *torque* M_t—to the drilling machine spindle (Fig. 21).

In this case, the torque will be the product of the force P (kg) multiplied by the diameter of the drill, D (mm). The drilling torque will then be expressed by the formula

$$M_t = 0.73\,PD \text{ kg/mm}.$$

In drilling, the feed force P and the torque M_t depend on the diameter of the drill D, the feed and on the material being drilled; for instance, with an increase in the drill diameter and the feed they will also increase.

The cutting power requirement during drilling, enlarging, core drilling and reaming can be calculated from the following formula:

$$N_{cut} = \frac{M_t \times n}{716{,}200 \times 1.36} \text{ kW}$$

where M_t is the torque, kg/mm

n is the tool speed, rpm.

Knowing the cutting power required for drilling (N_{cut}) and the output of the drilling machine motor (N_m), the efficiency of the machine tool may be calculated:

$$\eta = \frac{N_{cut}}{N_m}.$$

Heat in metal cutting and cooling the cutting tool during operation. Considerable heat is generated during the cutting process in drilling, as a result of the deformation of the metal, the friction of the chips against the flutes of the drill as they leave the hole, and the friction of the flank of the drill against the work surface. The greater portion of the heat is carried away together with the chips, while the remainder is distributed between the work and the tool.

Special cutting fluids, or coolants as they are called, are used for protecting the tool from being rapidly dulled and from premature wear due to heat. These fluids conduct

Table 5

Cutting Fluids Used in Drilling

Material drilled	Drilling: ordinary	Drilling: deep-hole
Carbon, structural, tool steel	1. Solution of soda in water 2. Solution of soda in water with admixture of: sodium nitrate, sodium orthophosphate, water glass 3. Solution of borax in water 4. Solution of soap in water	1. Soluble oil emilsion 2. Solution of alizarin oil in water 3. Sulphurized oil and kerosene 4. Sulphurized oil with kerosene and oleic acid
Steel castings	Soluble oil emulsion	
Cast iron	1. Dry 2. Soluble oil emulsion 3. Kerosene 4. Solution of borax and glycerine in water	—
Malleable cast iron	Soluble oil emulsion	—
Bronze	1. Dry 2. Soluble oil emulsion	—
Brass	1. Dry 2. Soluble oil emulsion	
Copper	1. Soluble oil emulsion 2. Mineral oil mixed with products containing fatty acids	—
Aluminium	1. Dry 2. Soluble oil emulsion 3. Kerosene	—

the heat away from the chips, the work and the tool. By lubricating the friction surfaces of the tool and the work, the fluid considerably reduces the friction, thereby facilitating the cutting process.

Table 5 lists the cutting fluids used in drilling different metals.

2. Selecting Cutting Speeds and Feeds in Drilling

Cutting conditions are selected to ensure the most efficient and economical cutting feeds and speeds for drilling.

The theoretical calculation of the elements of cutting conditions is effected as follows:

1. Feed is selected suitable to the nature of machining, the specified surface finish, the drill strength and the processing and mechanical properties of the work.

Then correct the feed selected from reference tables to correspond to one of the available values listed in the drilling machine specifications, taking the nearest (lower) value.

2. Then calculate the permissible cutting speed corresponding to the cutting properties of the drill. For drilling with high-speed steel drills the cutting speed is determined by the formula

$$v = \frac{C_v D^{z_v}}{T^m s^{y_v}} k \text{ m/min}$$

where C_v is a constant, depending on the metal and the machining conditions

D is the drill diameter, mm

T is the drill life, minutes

s is the feed, mm/rev

m is drill life exponent

z_v, y_v are exponents

k is general correction factor.

3. The drill speed, n, in rpm, is calculated (or selected from the table in Appendix 9), from the cutting speed thus obtained:

$$n = \frac{1{,}000v}{\pi D} \text{ rpm}$$

where D is the drill diameter, mm

v is the cutting speed, m/min

π is a constant, 3.14.

The drill speed thus obtained is corrected by data listed in the drilling machine specifications (the nearest smaller or higher value is taken providing it does not differ by more than 5 per cent from the calculated value).

4. The actual cutting speed, v_a, at which drilling will take place, is calculated:

$$v_a = \frac{\pi D n_a}{1{,}000} \text{ m/min}$$

where n_a is the speed, in rpm, corrected according to the machine specifications.

5. The selected cutting speed and feed are checked against the strength of the weakest link in the gear train of the drilling machine and the available power of its drive motor.

6. The basic machining time, t_0, is then calculated.

The machining time for one cut (pass) in drilling, hole-enlarging, core drilling or reaming is calculated from the formula

$$t_0 = \frac{L}{ns} = \frac{l + l_1 + l_2}{ns} \text{ min}$$

where L is the length of tool travel, mm

l is the hole length or depth, mm

l_1 is the length of travel required before the drill cuts to the full diameter, mm

l_2 is the overtravel, mm

n is the tool speed, rpm

s is the feed, mm/rev.

In drilling steel, cast iron and hard bronze with standard drills having a point angle $2\varphi = 116\text{-}118°$, $l_1 = 0.3\,D$ mm (where D is the diameter of drill in mm), and $l_2 = 0.5\text{-}3$ mm (for drill diameters from 2 to 60 mm).

When enlarging holes: $l_1 = 0.61\,tD$ mm (where t is the depth of cut in mm); l_2 will vary from 1 to 3 mm (for depths of cut from 2 to 25 mm).

When core drilling and reaming:

for tools having angle 2φ from 3 to 75°, D varies from 5 to 70 mm, t from 0.05 to 4 mm, l_1 from 0.05 to 7 mm;

for core drills $l_2 = 0.05\text{-}7$ mm;

for reamers $l_2=0.3$-0.5 of the length of the sizing section.

Usually, under production conditions, the cutting rates, drilling, core drilling, counterboring, countersinking, reaming and tapping feeds and speeds are selected from information given in the process sheets and reference tables.

An example of selecting cutting feeds and speeds for drilling is given below.

Example:

part—yoke;

operation—drilling a hole, diameter 28 mm for subsequent enlarging with a core drill;

machine tool—upright drilling machine, model 2A150;

tool—twist drill, diameter 28 mm, of high-speed steel of grade P18;

material to be machined—steel 45, tensile strength $\sigma_b=68$ kg/mm^2;

type of blank—drop forging;

weight of blank—2 kg;

method of clamping blank—on table without jig.

From Specifications of Drilling Machine, Model 2A150

Maximum drilling capacity—50 mm.

Spindle speeds, rpm—63; 89; 125; 185; 250; 350 and 500.

Power available on machine spindle, kW:

from drive—5.6;

from weakest link—not limiting factor.

Spindle feeds—0.12; 0.19; 0.28; 0.4; 0.62; 0.9; 1.17; 1.8 and 2.65 mm/rev.

Maximum force permitted by feed mechanism—2,500 kg.

Determining the Cutting Conditions

Selecting the geometry of the drill point. From Table 6 (page 110) the shape of the drill point is selected for machining steel with a tensile strength of $\sigma_b=68$ kg/mm^2, *Dw*—double angle with thinned web.

Selecting the feed. The feed for drilling steel with a tensile strength $\sigma_b=68$ kg/mm^2 with a drill of diameter $D=28$ mm is determined from Appendix 3. For rigid work to be drilled for subsequent machining, the feed will be

found in column "Feed Group I" corresponding to a steel of up to 50 kg/mm² tensile strength; it will be 0.45-0.55 mm/rev, and the nearest available feed on the machine is taken, 0.4 mm/rev.

The selected feed is checked against the force permitted by the strength of the drilling machine feed mechanism, the value of the axial cutting force being taken from Appendix 4. For drilling steel of $\sigma_b=68$ kg/mm² with a drill of diameter $D=28$ mm, and feed $s=0.4$ mm/rev, the axial force P will be 1,180 kg. The machine allows a force of 2,500 kg, therefore the chosen feed is permissible.

Determining the Cutting Speed

1. The machinability group of the steel is determined from Appendix 5. Grade 45 carbon steel, with an ultimate strength σ_b of 68 kg/mm² belongs to the 5th machinability group.

2. The cutting speed for drilling a steel of the 5th group is then found. The cutting speed, v, for drilling a hole of diameter $D=28$ mm, and 60 mm long with a drill of grade P18 steel, using a feed $s=0.4$ mm/rev, will be 27.5 m/min.

3. The spindle speed n in rpm is obtained from the following formula:

$$n=\frac{v\times 1{,}000}{\pi D}=\frac{27.5\times 1{,}000}{3.14\times 28}=312 \text{ rpm}.$$

350 rpm, the nearest spindle speed available on the drilling machine, is taken.

Under these conditions the actual cutting speed v will be:

$$v=\frac{\pi Dn}{1{,}000}=\frac{3.14\times 28\times 350}{1{,}000}=30.8 \text{ m/min}.$$

Chapter VII

TOOLS, JIGS AND FIXTURES

1. Tools for Machining Holes

Holes are machined in drilling machines with the aid of various cutting tools: drills, core drills, counterbores, countersinks, reamers, boring tools and taps.

Drills are used for originating holes in various materials. The following types of drills are distinguished:

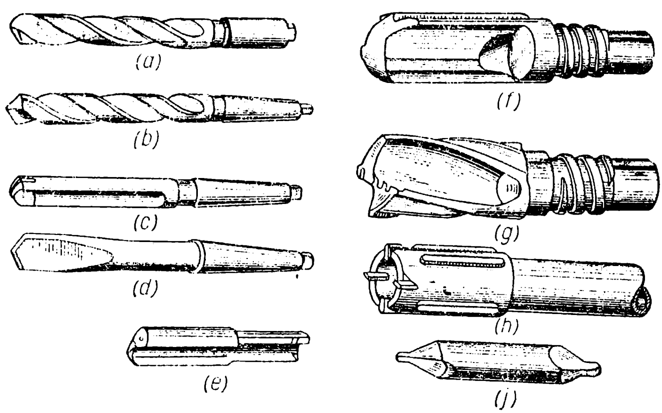


Fig. 22. Types of drills:

(a) and (b) twist drill, (c) straight-flute drill, (d) flat drill, (e) gun drill, (f) single-lip drill, with internal chip removal, (g) double-lip drill, (h) trepanning drill, (j) combined drill and countersink

(1) twist drills, (2) straight-flute drills, (3) flat drills, (4) deep-hole drills, (5) trepanning drills, (6) combined drills and countersinks.

Drills are made of high-speed, alloy and carbon steels, and may be tipped with cemented carbides.

Different types of drills are shown in Fig. 22.

Twist drills are used most widely in industry. Before the appearance of twist drills, holes were made with flat drills, which required considerable effort; moreover, the chips would choke the hole. These drills were made of carbon steel, and their cutting edges (or lips) could not withstand heating to temperatures over 250° C; cutting speeds were limited to 2-3 m/min. At the present time

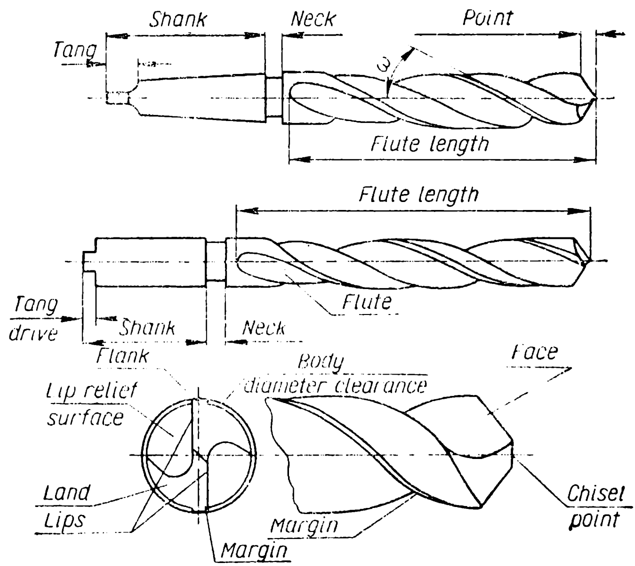


Fig. 23. Parts and elements of a twist drill

twist drills are mainly used. They are of superior design which facilitates better removal of chips.

Twist drills (Fig. 23) are made with diameters from 0.1 to 80 mm. They consist of a body, a shank (tapered or straight) for holding the drill in the machine spindle or in a drill chuck, and a tang for forcing the drill out of the socket with a drift.

The *body* of the drill is a cylinder with two helical flutes along which the chips leave the hole being drilled.

The *point* is the cutting end of the drill made up of the lands and the web. In form it resembles a cone, but departs from a true cone to furnish clearance behind the

cutting lips which are joined by the *chisel point* at an angle of 55°.

On the cylinder are two narrow helical *margins* in front of the lands; they serve to locate the drill and to guide it properly in the hole.

These margins considerably reduce the friction between the drill and the walls of the hole. In addition, the body of the drill has a back taper towards its shank (the drill

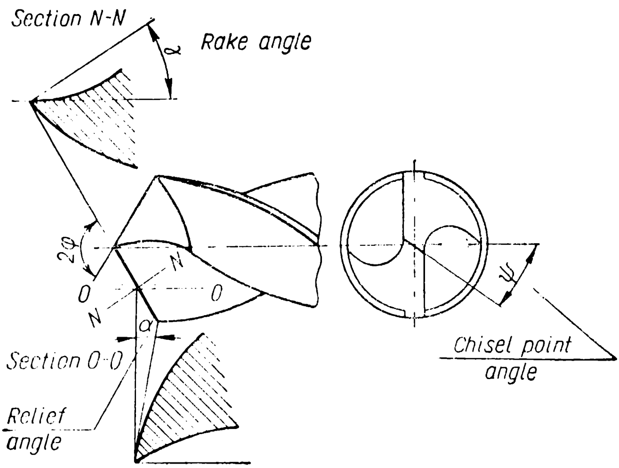


Fig. 24. Drill point geometry

diameter falls off by from 0.03 to 0.1 mm per 100 mm of length), for reducing its friction in the hole.

The efficiency of all cutting tools, including drills, depends on the material from which they are made, their heat treatment and on the angles to which their cutting lips are ground.

The angles at the point of a drill (Fig. 24) are: the rake angle γ (gamma), the lip relief angle α (alpha), the point angle 2φ (phi), the chisel or edge point angle ψ (psi) and the flute helix angle ω (omega) (the latter is shown in Fig. 23).

The *rake angle* γ is the angle measured in plane *NN*, perpendicular to the lip. The rake angle will vary at various points along the lip, being greatest at the periphery of the drill, and least at its chisel point. The rake

angle at the drill chisel point will be from 1 to 4°. This variable rake angle is one of the drawbacks of twist drills and is one of the factors promoting uneven and rapid wear.

The *lip relief angle* α is measured in the plane *OO*, parallel to the axis of the drill. Like the rake angle, it is also variable. It increases from 8-12° at the periphery of the drill to 20-25° at the drill centre. The lip relief angle reduces friction between the surfaces behind the cutting lips and the cutting surface.

The *point angle* 2φ is measured between the cutting edges (lips) and depends on the material being machined. For machining steels, angle 2φ is usually from 116 to 118°.

For drilling hard materials angle 2φ will be 130-140°, and for drilling soft and tough materials, from 125 to 140°.

The *chisel or edge point angle* ψ in standard twist drills ranges from 50 to 55°.

The *flute helix angle* ω affects the rake angle α, and makes the cutting process easier, facilitating the escape of the chips from the hole and along the flutes.

The helix angle is selected to correspond to the drill diameter and the properties of the material being drilled. For nonferrous metals (copper, aluminium, and others) it ranges from 35 to 45°, and for steel—up to 30°. Irrespective of the material being drilled, the flute helix angle ranges from 25 to 30°.

The *flat drill* (see Fig. 22*d*) is now comparatively rarely used. The head of the drill is flattened from one end of a rod and has two cutting edges or lips, arranged at a point angle of 120°.

Drills for deep-hole drilling are used mainly for drilling through or blind holes in shafts, spindles and other parts of considerable length. Although they have comparatively low efficiency, they produce straight, true holes with a good finish.

Drills of this type include: half-round drills (Fig. 25*a*), gun drills (Fig. 22*e*), single-lip (Fig. 22*f*), and double-lip (Fig. 22*g*) drills with internal chip removal.

Half-round and gun drills are used for drilling holes of relatively small diameter; single- and double-lip drills are used for drilling medium and large holes.

Trepanning drills (Fig. 25*b*) are used for drilling large holes over 50 mm in diameter. They consist of a

hollow head, with inserted blades and wear strips. The head is screwed onto a taper-threaded arbour.

Combined drills and countersinks (Fig. 26*a*) are used for drilling centre holes in various blanks. They are available either as the plain or bell types.

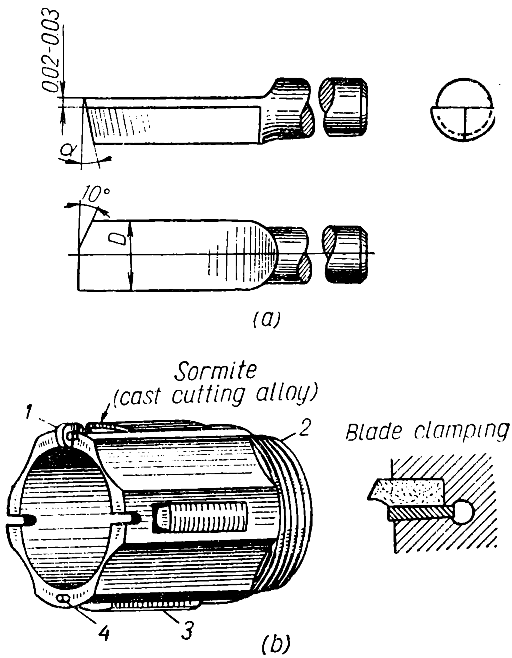


Fig. 25. Gun drill (*a*) and trepanning drill (*b*):
1—blade, *2*—taper thread, *3*—wear strip, *4*—blade slot

Carbide-tipped drills (Fig. 26*b* and *c*) have longer life and ensure high efficiency as they can be used at high cutting speeds. They can be used for drilling soft and hardened steels, cast irons, plastics, glass and other materials. They are manufactured with straight or helical flutes. The drill body is made of alloyed or carbon tool steel. The cemented-carbide tips are brazed into the lips of the drill with copper or brass brazing filler metal.

Drills tipped with grade BK8 cemented carbide are used for drilling cast iron, and those tipped with grade T15K6 cemented carbide—for drilling hardened steels.

Straight-flute drills are usually employed for drilling cast iron and other brittle materials, while drills with helical flutes are used for drilling tough materials.

Core drills are used for opening out, or enlarging rough forged, cast or previously drilled holes.

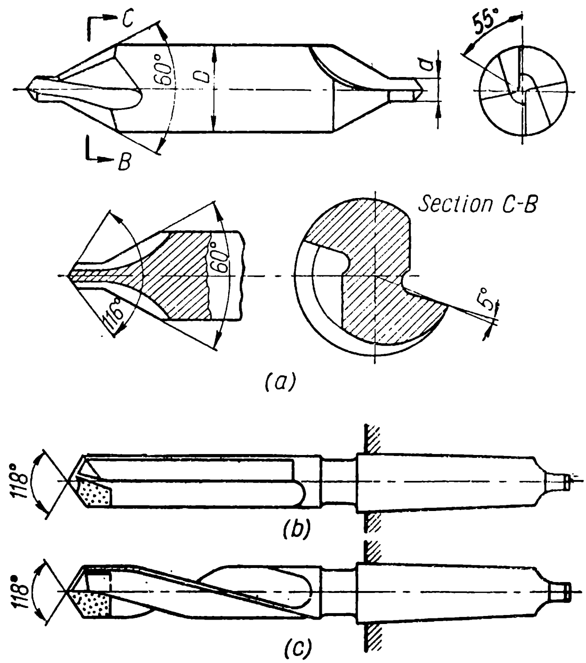


Fig. 26. (*a*) combined drill and countersink, (*b*) straight-flute carbide-tipped drill, (*c*) helical-flute carbide-tipped drill

These drills (Fig. 27) differ from twist drills in that they have three or four flutes, or cutting lips, and no chisel point on the web.

Like twist drills, core drills are fluted. The helix angle of the flute is selected to suit the material being machined; hard materials require a larger angle than relatively soft materials. The helix angle of the flute for general-purpose core drills ranges from 10 to 30°. For machining cast iron this angle is usually taken as zero. For carbide-tipped core drills, a flute helix angle of from 10 to 20° is recommended.

The rake angle γ plays an important part in core drilling operations; cutting is made easier if this angle is increased. In high-speed steel core drills for machining steel of medium hardness and steel castings the rake angle ranges from 8 to 12°; in core drills for cast iron of medium hardness it ranges from 6 to 8°.

In carbide-tipped core drills for machining cast iron $\gamma = +5°$; for machining steel of medium hardness the angle γ of such core drills will be between 0 and $-5°$.

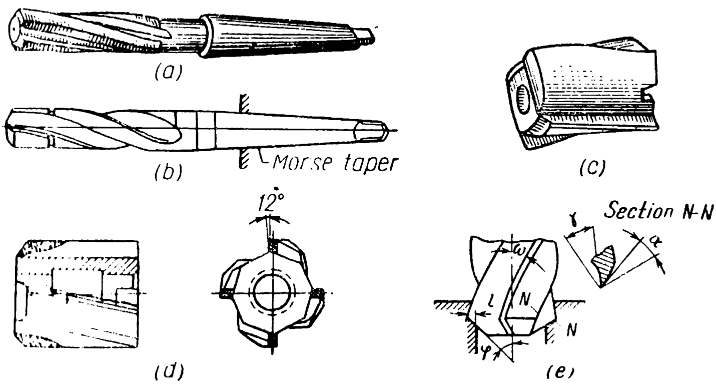


Fig. 27. Core drills:

(a) helical-flute, made of high-speed steel, (b) helical-flute, tipped with cemented carbide, (c) high-speed steel shell core drill, (d) carbide-tipped shell core drill, (e) main angles of core drills

The lip relief angle α on the chamfered cutting edge is determined by the feed and the thickness of the layer being removed. For high-speed core drills α ranges from 6 to 10°, and for carbide-tipped core drills, from 10 to 15°.

There are two types of core drills: (1) the *solid, taper-shank* core drill, and (2) the *shell* core drill which is mounted on an arbour; shell core drills, in turn, are classified as solid and inserted-blade shell core drills.

The body of solid core drills is made of high-speed steel, butt-welded to a tapered shank of structural steel. The blades of shell core drills may be either of high-speed steel or tipped with cemented carbide.

Solid core drills, like the twist drills, are inserted into the tapered hole of the drilling machine spindle; shell core drills are mounted on special arbours with tapered shanks

for inserting into the tapered hole of the drilling machine spindle. Solid core drills with tapered shanks are made with three flutes and are used for machining holes up to 35 mm in diameter. Shell core drills are made with four flutes and are used for machining holes up to 100 mm in diameter.

Reamers, Fig. 28, are used for finishing holes in order to give them a high dimensional accuracy and high surface finish. The starting taper, or secondary chamfer of the reamer is inclined to the axis at an angle φ and performs the main cutting work. For reaming holes in ductile metals, angle φ will range from 12 to 15°; for reaming holes in hard, brittle metals, angle φ will range from 3 to 5°.

In carbide-tipped reamers, angle φ ranges from 30 to 45°; the chamfer of the reamer is at an angle of 45°; it guides the reamer into the hole and protects its teeth against damage. The relief angle α of the starting taper ranges from 6 to 15°. In the sizing section, angle α is usually zero. The rake angle γ ranges from 0 to 15°. For brittle materials $\gamma=0°$ while for carbide-tipped reamers, rake angle γ ranges from 0 to —5°.

Reamers are classified as hand and machine reamers, cylindrical and taper reamers, shell and solid reamers, according to their design and application.

Hand reamers are made with a straight (cylindrical) shank and are used for reaming holes ranging from 3 to 50 mm in diameter, by hand.

Machine reamers are made with straight or taper shanks and are used for reaming holes with diameters from 3 to 100 mm. Holes are machined with these reamers in drilling machines and lathes.

Shell reamers are used for reaming holes with diameters from 25 to 100 mm. They are mounted on special arbours with taper shanks for inserting into the machine spindle. Shell reamers are made of grade P9 or grade P18 high-speed steel.

Taper reamers are used for reaming tapered holes. Usually a set of three reamers is used: the roughing, semifinishing and finishing taper reamers.

Solid reamers are made from carbon or alloy tool steel.

Carbide-tipped reamers are used for reaming holes in hard metals. They have greater wear resistance than high-speed steel reamers.

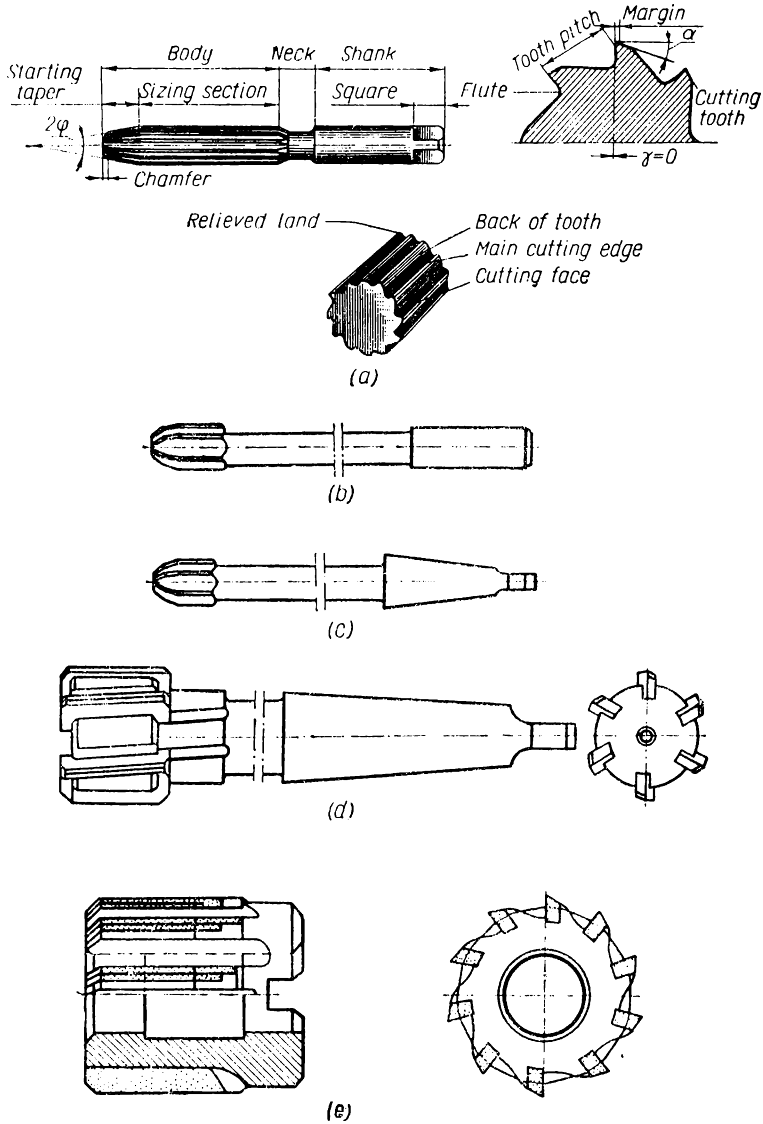


Fig. 28. Types of reamers:

(*a*) reamer parts and elements, (*b*) straight-shank machine reamer, (*c*) taper-shank machine reamer, (*d*) inserted-blade reamer, (*e*) carbide-tipped shell reamer

Taps are used for cutting internal threads. A tap has the form of a screw with several longitudinal straight or helical flutes which form the cutting edges and provide a space for the escape of the chips.

According to their design and purpose taps are classified as:

hand taps for cutting metric, English and pipe threads by hand. They are supplied in sets of two or three;

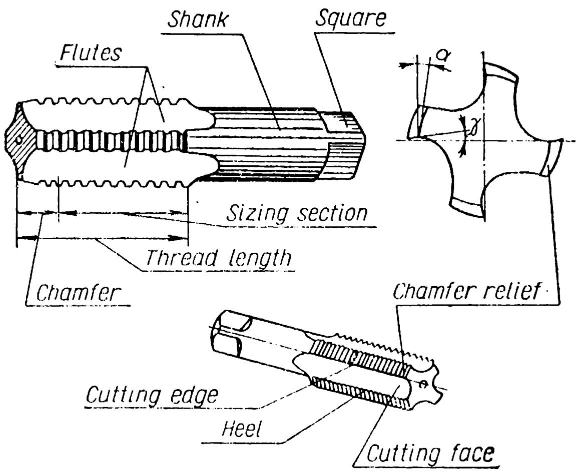


Fig. 29. Parts, surfaces and cutting elements of taps

nut taps (long and short) for cutting metric and English threads in nuts and through holes in various workpieces, usually on drilling machines. Bent-shank tapper taps are used for cutting threads in nuts on automatic tapping machines. They may also be used on drilling machines, with special attachments for the continuous tapping of nuts;

machine taps are intended for cutting metric, English and pipe threads in through or blind holes in drilling machines fitted with a spindle rotation reversing mechanism.

A tap (Fig. 29) consists of a body and a shank. The *body* of a tap consists of the chamfer and the sizing section. The thread, after being cut by the chamfer, is finished by the sizing section.

The *shank* has a square for inserting the tap into a chuck or tap holder.

The *flutes* serve for the escape of the chips, and form the faces and heels of the lands, or teeth.

Taps are made of carbon, alloy and high-speed tool steels.

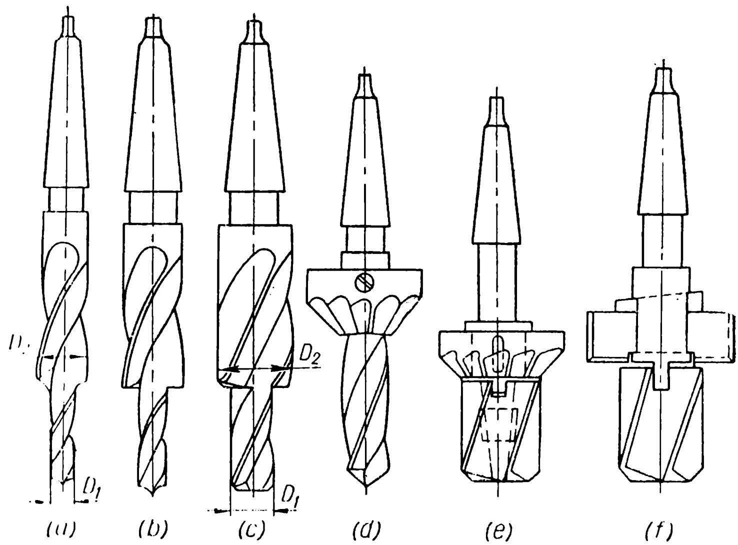


Fig. 30. Combination tools:

(*a*) and (*b*) two-diameter drills, (*c*) stepped core drill (counterbore), (*d*) combination drill and countersink, (*e*) combination shell core drill and countersink, (*f*) combination shell core drill and spotface

Combination tools (Fig. 30). Large-lot and large-scale production requires the use of combination multiple diameter or multistep cutting tools such as stepped drills, stepped core drills, etc. Two or three stepped holes can be obtained in one operation with these tools.

For example, a combination drill and countersink (Fig. 30*a*) is used for drilling a hole and countersinking for a flat head screw or for cutting a chamfer.

A combination drill and counterbore (Fig. 30*b*) are used for drilling a hole and machining an internal face.

For enlarging two holes of different diameters a stepped core drill is used (Fig. 30*c*).

When a previously drilled hole is to be enlarged and countersunk, a combination core drill or twist drill and countersink is used (Fig. 30 *d* and *e*).

In order to enlarge a hole and to machine the face of the boss, a combination core drill and spotfacer is used (Fig. 30*f*).

Combination tools considerably reduce hole machining time since the number of operations and the handling and machining time are reduced.

2. Drill Wear, Life and Sharpening

Drills, like all other cutting tools, wear out in the process of cutting metals.

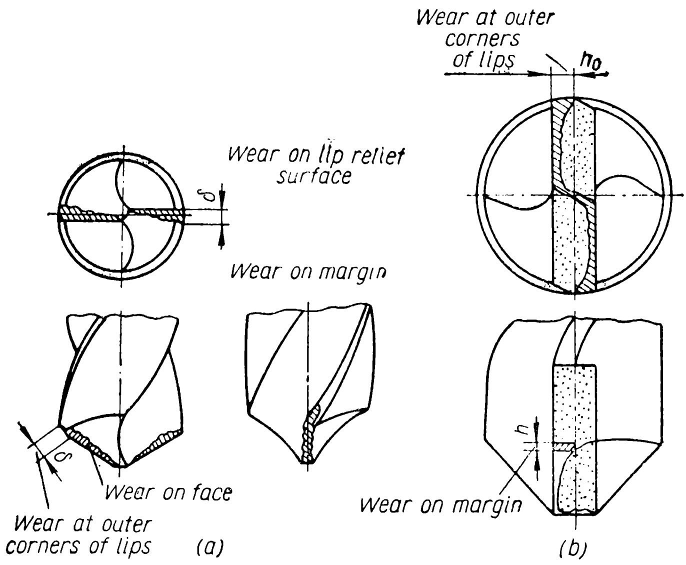


Fig. 31. Nature of wear on a drill:

(*a*) wear of high-speed steel drill, (*b*) wear of carbide-tipped drill

The *wear* of high-speed steel drills takes place on the relief surface, margins, end of lips (corners) and sometimes on the face surfaces (Fig. 31*a*); carbide-tipped drills wear at the relief surfaces, end of lips (corners) and web (Fig. 31*b*).

The relief surfaces of the drill are worn by rubbing against the cutting surface; the face surfaces, by the abrasive action of the chips formed during drilling. The permissible average wear of the cutting edges of certain tools is given in Appendix 7.

The *life* of a drill is the time during which the drill is in continuous operation before it is dulled, i.e., the time, in minutes, between two grinds.

Drill life depends on the material being drilled, the material of which the drill is made, its heat treatment, the surface finish of its lips, on its cutting conditions (especially cutting speed and feed), on the cutting fluid used, and on other factors. The faster the wear of the face and the relief surfaces, the margins and corners (the points where the lips merge into the margins), the shorter the life of the drill. Average drill life periods are given in Appendix 6.

Drill sharpening. The form to which the point of the drill is ground greatly influences the life of the drill and the permissible cutting speed. The following types of drill points are distinguished: single angle (conventional) and double angle drill points; thinned web, relieved margin, and other forms (Table 6).

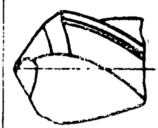
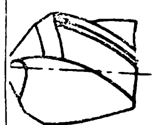
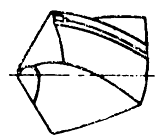
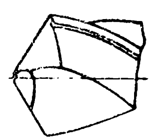
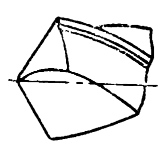
The principal angles of *conventional point drills* are given in the description of the geometry of the drill point.

In a *double angle drill*, the lip is ground to form two sections; the second relieved section, is short and has an included angle 2φ of 70 to 75°, the longer section near the tip has the standard 116 to 118° point angle. The life of a double angle drill is increased by 2.5 to 3 times in drilling steel and 5 to 6 times in drilling cast iron, as compared to drills with conventional points.

Margin relieving is effected by grinding relief on the margin for a length of 1.5-4 mm at an angle of 6 to 8°, leaving a narrow cylindrical margin from 0.1 to 0.2 mm wide, which is necessary to prevent the drill from binding and breaking. This method of grinding increases the drill life from 2 to 3 times in drilling ductile steels.

Web thinning consists in grinding additional recesses in the drill point from both sides along its axis for a length of 3 to 15 mm, depending on the drill diameter, and thereby reducing the length of the chisel point to 0.1 of the drill diameter, *D*. This results in a considerable

Types of Drill Points

Drill diameter, mm	Grinding shapes			Machined material
	designation	index	sketch	
0.25 to 12	Single angle (conventional)	C		Steel, steel castings, cast iron
	Single angle with thinned web	SW		Steel castings with tensile strength σ_b up to 50 kg/mm^2, with skin not removed
Over 12 and up to 80	Single angle with thinned web and relieved margin	SWM		Steel and steel castings with ultimate strength σ_b up to 50 kg/mm^2, with skin removed
	Double angle with thinned web	DW		Steel castings with tensile strength σ_b over 50 kg/mm^2, with skin not removed; cast iron with skin not removed
	Double angle with thinned web and relieved margin	DWM		Steel and steel castings with tensile strength σ_b over 50 kg/mm^2, with skin removed; cast iron with skin removed

reduction in the feed pressure, and in an approximately 50 per cent increase in the drill life.

Many innovators of production in the Soviet Union are engaged in improving the design of drills to ensure higher cutting conditions and to increase drill life. Thus, drills

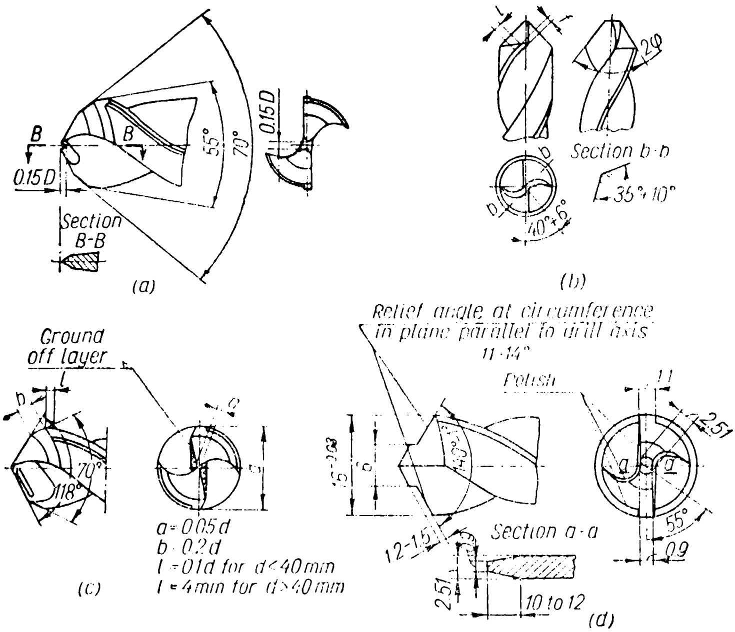


Fig. 32. Methods of sharpening drills developed by drilling-machine operators:

(*a*) high-speed steel drill designed by V. Zhirov, (*b*) sharpening suggested by V. Kostyr, (*c*) drill designed by A. Medikov, (*d*) step-ground drill suggested by V. Karasev

are now ground by the method developed by V. Zhirov, a Soviet drilling machine operator; this method (see Fig. 32*a*) consists in grinding a groove in the web of the drill to a depth equal to 0.15 *D* (the drill diameter). As a result, the entrance of the drill into the work is facilitated; moreover, the feed pressure is reduced by 50 per cent, and the speed of drilling holes increases by 100 to 150 per cent.

V. Kostyr, another drilling machine innovator, has suggested a special method of grinding drills; the special feature of his method is the formation of a new type of chisel point at the strongest cross section of the lands (see Fig. 32*b*).

For drilling holes in ductile steels, a point angle 2φ of 130° is recommended; and an angle 2φ of 118 to 120° for drilling holes in grey cast iron.

Grade P9 high-speed steel drills, ground by V. Kostyr's method, are distinguished for their long life and are capable of working at heavy feeds.

Fig. 32*c* shows a drill designed by A. Medikov, with a chip-breaking groove ground in the face surfaces. This drill is recommended for drilling holes in ductile metals (brass and mild steel), and permits an increase of 150 to 200 per cent in the feed rates.

Fig. 32*d* shows a step-ground drill suggested by V. Karasev. This drill ensures higher drilling accuracy and surface finish, and can be used at high cutting speeds and heavy feeds. No jigs are necessary when using this drill, and there is no danger of departure from the true hole axis during drilling.

Table 6 lists the various types of drill points which can be applied, depending on the diameter of the drill and the material being drilled.

Hand sharpened twist drills cannot ensure good quality of holes, as it is practically impossible to grind both lips of the drill to exactly the same length.

Superior results are obtained if drills are sharpened in special drill point sharpening machines or by using special attachments for ordinary grinders.

Carbon and high-speed steel tools used for machining holes (drills, core drills, countersinks, reamers, taps, etc.) are ground with vitrified bonded standard and white aluminium oxide grinding wheels grade CM and grain size from 36 to 46 grit (for rough sharpening) and from 60 to 80 grit for finish sharpening.

Carbide-tipped tools are ground with green silicon carbide wheels having a grain size from 36 to 46 grit (for rough sharpening) and from 60 to 80 grit for finish sharpening.

After sharpening, the cutting edges are lapped on lapping wheels with boron carbide powder.

The main faults in drill sharpening include:

(1) The cutting lips are of unequal length, as a result of which the axis of the drill does not pass through the center of the chisel point, and the load on the lips will be uneven; the hole will be cut oversize, i.e., its diameter will be greater than that of the drill as a result of the runout of the drill.

(2) The cutting lips are of equal length but make unequal angles with the axis of the drill; as a result, the

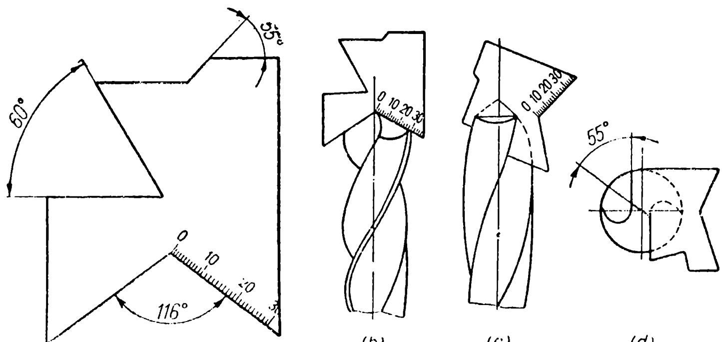


Fig. 33. Combination drill gauge:

(a) gauge, (b) checking the point angle and length of the lips, (c) checking the lip angle, (d) checking the chisel point angle

drill axis does not coincide with the centre of the chisel point; the lips of the drill are unevenly loaded and the hole will be drilled oversize as a result of runout of the drill.

(3) The web is unequally thinned from the two sides; the drill axis does not pass through the centre of the chisel point, causing the drill to runout, as a result of which the hole will be cut oversize.

After sharpening, drills are checked with a special combination gauge (Fig. 33). The helix angles of twist drill flutes, drill point angles, and the dimensions of point elements are given in Tables 7 and 8.

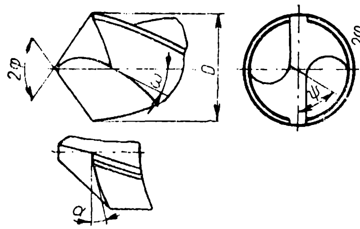
3. Tool-Holding Accessories

Drills, reamers, core drills and similar cutting tools are held in drilling machine spindles with such accessories as: drill sleeves, drill chucks, arbours, etc.

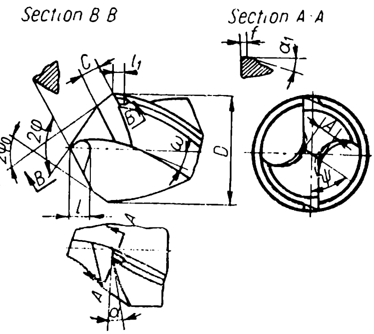
Table 7

Dimensions of Point Elements of a Twist Drill

Sketch 1



Sketch 2



Helix Angles of Twist Drill Flutes

Drill diameter, mm	from 0.25	.4	0.5	0.75	1.0	2.0	3.0	3.5	4.5	6.5	8.5	10
	to 0.35	0.45	0.7	0.95	1.9	2.9	3.4	4.4	6.4	8.4	9.4	80
Helix angle ω, degrees	18	19	20	21	22	23	24	25	26	27	28	30

Notes. 1. Maximum permissible error in angle ω . . . . . . —2.
2. The shape and notation of the dimensions of thinned webs and relieved margins, shown in sketch 2, refer to both double angle and conventional points.

Taper sleeves are used for holding cutting tools with taper shanks when the Morse taper of the tool shank is smaller than that of the hole in the drilling machine spindle.

The external and internal surfaces of taper sleeves are, according to U.S.S.R. State Standards, Morse tapers ranging from No.0 to No.6. If the taper of a drill shank is smaller than that of the hole of the drilling machine spindle, the shank of the drill is inserted into a sleeve which fits the taper hole in the spindle. If one sleeve is insufficient, several sleeves are used, each sleeve fitting into the next, larger one.

Drill Point Angles and Elements

Drill diameter, mm	Conventional and double angle points				Web thinning			Margin relief		
	Point angles		Lip relief angle, α	Chisel-point angle, ψ	Length of second lip, B	Thickness of thinned web, A	Length thinned, l	Length relieved, l_1	Width of cylindrical margin, f	Angle of relief α_1, deg.
	2φ	$2\varphi_0$								
	in degrees				in millimetres					
From 0.25 to 12 .	—	—	—	—	—	—	—	—	—	—
Over 12 to 15 . .	—	—	14-11	50	2.5	1.5	3	1.5	—	—
„ 15 „ 20 . .	—	—	—	—	3.5	2	4	1.5	—	—
„ 20 „ 25 . .	—	—	12-9	—	4.5	2.5	5	2	—	—
„ 25 „ 30 . .	118	70	—	55	5.5	3	6	2	0.2-0.4	6-8
„ 30 „ 40 . .	—	—	—	—	7	3.5	7	3	—	—
„ 40 „ 50 . .	—	—	—	—	9	4	9	3	—	—
„ 50 „ 60 . .	—	—	11-8	—	11	5.5	11	4	—	—
„ 60 „ 70 . .	—	—	—	—	13	6.5	13	4	—	—
„ 70 „ 80 . .	—	—	—	—	15	7.5	15	4	—	—

Note: Permissible error: angle $2\varphi = \pm 2°$
angle $2\varphi_0 = \pm 5°$
dimensions B, A, l and l_1 $+0.5$ mm

Drill chucks are used for holding straight-shank drilling tools with diameters up to 15 mm.

Fig. 34*a* illustrates a *three-jaw chuck* in which drills are clamped with the aid of a wrench.

The body of the chuck (Fig. 34*b*) houses three threaded inclined jaws *1* mating with nut *2*. Ring *3* is rotated by special wrench *4*, inserted into a hole in the body of the chuck. When the ring is turned clockwise, the nut rotates and the clamping jaws, moving downwards, gradually

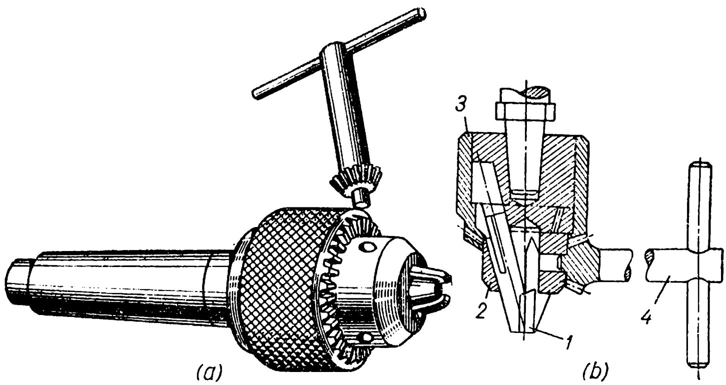


Fig. 34. Drill chuck for holding straight-shank drills

contact and clamp the straight shank of the drill or whatever tool is being used. On being turned in the opposite direction, the jaws, travelling upwards, open out to release the tool.

Two-jaw drill chucks, like three-jaw chucks, are used for clamping straight-shank tools in drilling machines. The tool shank is held fast in these chucks by two sliding jaws travelling in T-shaped grooves in the body of the chuck; they are opened and closed by a wrench-operated screw having a left- and right-hand thread.

Collet-type drill chucks are often used for holding small-diameter straight-shank drills for large-scale production.

Fig. 35*a* illustrates such a collet chuck; it comprises a body with a tapered shank *1* at one end for holding the chuck in the drilling machine spindle, and a threaded and taper-bored cylindrical section *2* of larger diameter at the other end.

Screwed onto the threaded section of the chuck is collar *4*, having a shoulder which fits the front end of the collet. The collar is knurled to facilitate clamping the drill

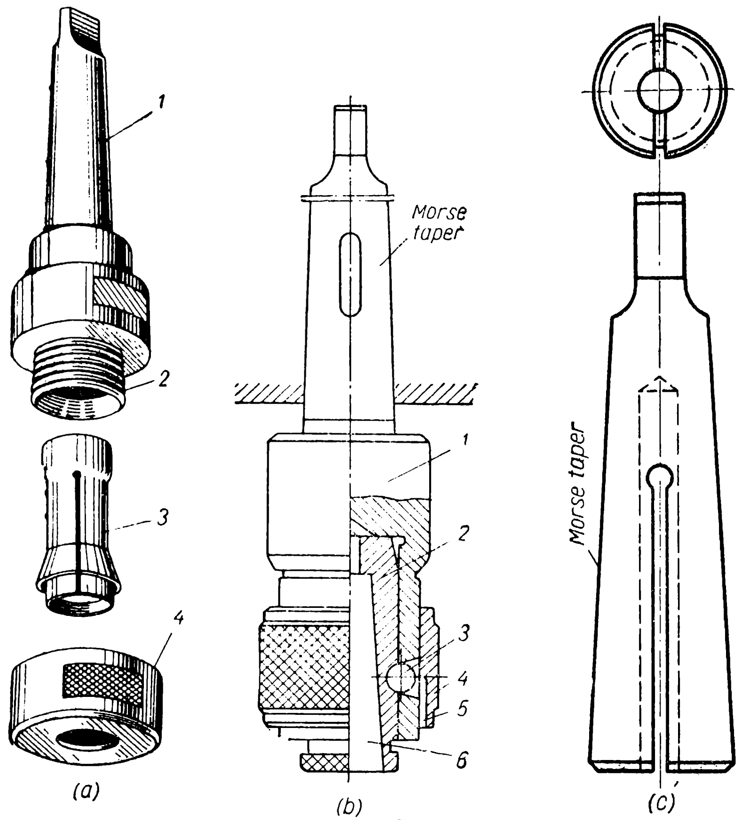


Fig. 35. Collet-type drill chuck (*a*), quick-change drill chuck (*b*), split taper sleeve for straight-shank drills (*c*)

by hand. Taper spring collet *3*, with a cylindrical bore corresponding to the tool diameter, is inserted into the taper hole of the chuck body. When the collar is screwed onto the threaded portion of the chuck body, the leaves of the split collet are contracted, thereby clamping the drill shank. The tool is released by turning the clamping collar

in the opposite direction, in which case the spring collet spreads.

Quick-change drill chucks are used for reducing handling time in operating drilling machines. They enable tools to be rapidly changed without stopping the machine. A quick-change chuck for taper-shank tools is shown in Fig. 35*b*.

The taper-shank cutting tool is inserted into the correspondingly tapered bore *6* of interchangeable sleeve *2* which is then inserted into the cylindrical bore of chuck body *1*. For this, body collar *4* is raised to its upper position, when two balls *3* enter the hole in chuck body *1* and a recess *5* in collar *4*. As the collar is lowered, its inner surface forces the balls into the recesses in interchangeable sleeve *2*, thereby rigidly securing the sleeve together with the tool in the body of the chuck.

The tool can be changed without stopping the machine; for this purpose, collar *4* is raised with the left hand to its extreme upper position and the balls forced outward under the action of the centrifugal force. Sleeve *2*, together with the tool, can then be easily removed from the chuck body with the right hand.

Each chuck must be supplied with a set of taper sleeves of various sizes of Morse tapers.

Split taper sleeves have recently come into wide use in lot and large-scale production for securing straight-shank drills up to 10 mm in diameter.

The distinguishing feature of these sleeves is their tapered surface and the slit, which passes through the axis of the bore of the sleeve (Fig. 35*c*). These sleeves ensure rigid clamping of drills in the drilling machine spindle.

Self-aligning drill chucks (see Fig. 36) are used for machining previously drilled holes. They ensure the correct alignment of the cutting tool with the axis of the hole.

Taper-shank chuck body *1* is inserted into the drilling machine spindle and transmits rotation to sleeve *6* through driver *3* located in two blind hexagonal holes. Ball thrust bearing *4* is mounted between the end of the chuck body and the head of the sleeve. The body and the sleeve are connected by coupling *7*, screwed over the thread of the sleeve. Lock nut *5* prevents the coupling

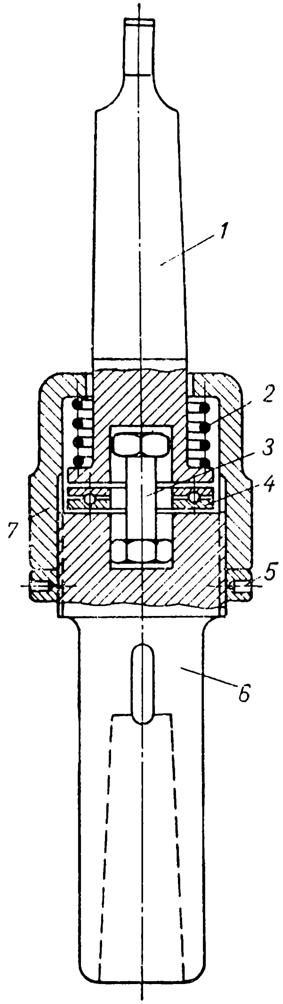


Fig. 36. Self-aligning drill chuck

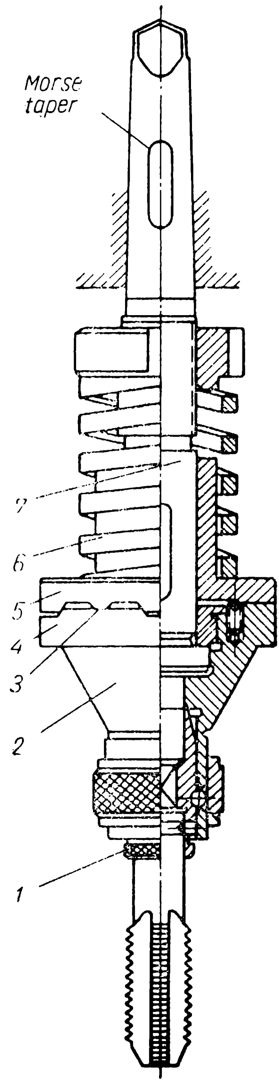


Fig. 37. Safety tap chuck for tapping blind and through holes

from rotating on the chuck sleeve. Helical spring *2* is located inside the coupling; one end of this spring thrusts against the shoulder of the body, and its other end—against the coupling, thereby holding together the sleeve and chuck body. This arrangement permits the chuck

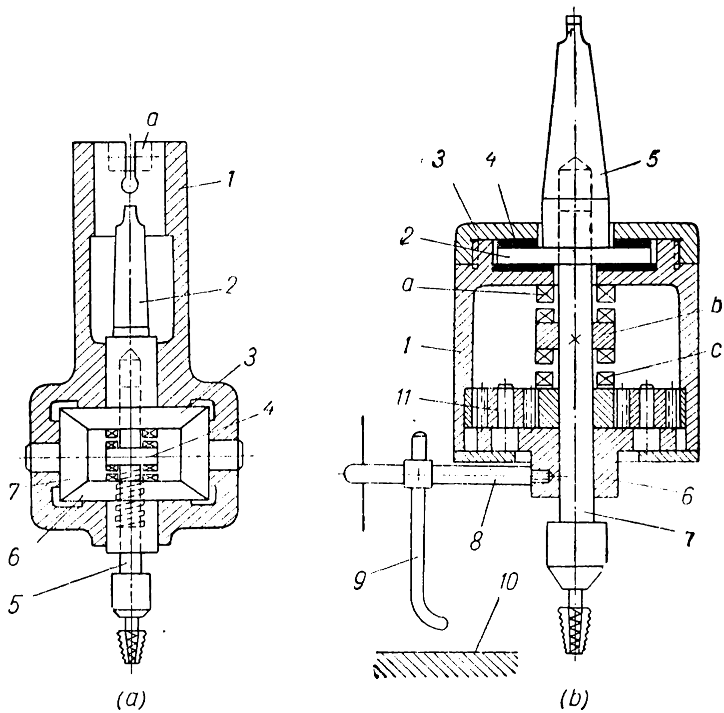


Fig. 38. Reversing chuck:
(*a*) standard, (*b*) rapid reverse chuck

sleeve to align itself with the preliminary drilled hole during operation.

Safety tap chucks are used for securing taps in drilling spindles for cutting threads. The use of these chucks improves the quality of the thread and prevents breakage of the taps.

The design of such a safety tap chuck is shown in Fig. 37. Driving clutch member *5* is forced by spring *6* against driven clutch member *2* which is mounted freely

on central shaft 7. Jaws 3 of clutch member 5 engage similar jaws 4 of clutch member 2 thereby rotating the latter. On the completion of the tapping operation, clutch member 2, together with the tap, ceases to rotate, while clutch member 5 becomes disengaged from clutch member 2 after compressing spring 6 and, continuing to rotate, commences to slip, making a clicking noise. The tap is then withdrawn from the tapped hole by reversing the spindle. Collar 1 fixes the tap in the chuck.

Reversing chucks are used for tapping holes on drilling machines not equipped with reversing devices. The taps can be screwed out of the tapped holes by simply reversing the chuck.

Reversing chuck body 1 (see Fig. 38*a*) is clamped on the drilling machine spindle. During the tapping operation, rotary motion is transmitted from the spindle to chuck shank 2, and thence through clutch 4 to shaft 5. When the body is raised at the beginning of the reverse motion, the clutch shifts to its lower position and the transmission of rotation to shaft 5 is reversed through bevel gears 3, 7 and 6.

Fig. 38*b* shows a reversing chuck of more modern design. Rotation is transmitted from the drilling machine spindle to the chuck body 1 through taper shank 5, disk 2 and friction linings 4, which are compressed by nut 3. Shaft 7, together with the tap, is rotated by clutch jaws *a* and *b*. The lower section 6 of the chuck is prevented from rotation by pin 8 which slides in a vertical groove in the machine column or body of a drilling jig.

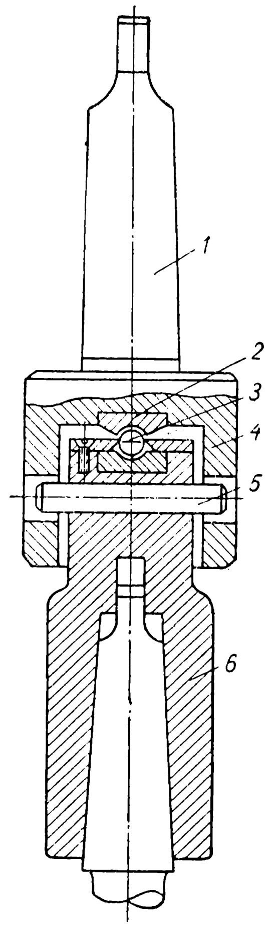


Fig. 39. Floating holde for a reamer

Pin *8* has a stop *9* the height of which can be adjusted to the required length of thread. When this stop contacts the stationary surface *10*, the chuck ceases to descend and the tap, continuing its cutting action, draws shaft *7* downwards, thereby disengaging clutch jaws *a* and *b* and engaging jaws *b* and *c*. Reverse motion is transmitted to the tap through idle gears *11* at a higher speed. Breakage of the tap is prevented by the slipping of disk *2*, located between the friction linings *4*.

Fig. 39 illustrates a *floating holder* for a reamer. Its taper shank *1* is inserted in the tapered bore of the drilling machine spindle. The end of socket *6* sits freely in the hole of holder *4*, where it is held by driving pin *5*, which also sits freely in the holes of the holder. The feed pressure is transmitted to socket *6* through hardened ball *3* and thrust block *5*. The reamer, inserted in the floating part of the holder can easily take a position coinciding with the axis of the hole being reamed.

4. Jigs and Fixtures

Various jigs and fixtures and other accessories are used for properly mounting and clamping workpieces on drilling machine tables. Among the most common are: ma-

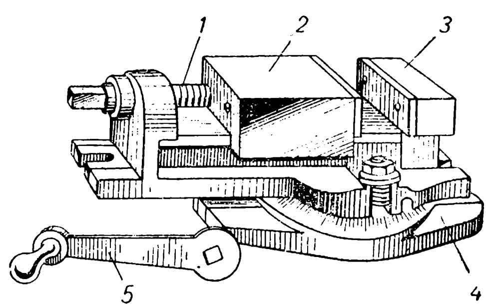


Fig. 40. Machine vise

chine vises (screw, cam and pneumatically operated vises), vee-blocks, stationary stops, angle plates, jigs and special fixtures.

Screw-type machine vises (Fig. 40) are widely used in piece production. They comprise base *4*, bolted to the

machine table, movable jaw *2*, stationary jaw *3*, screw *1* and handle *5*. The workpiece is clamped between the jaws by turning the handle, which rotates the screw.

Cam-type machine vises ensure quicker clamping of the workpiece than can be obtained with a screw vise

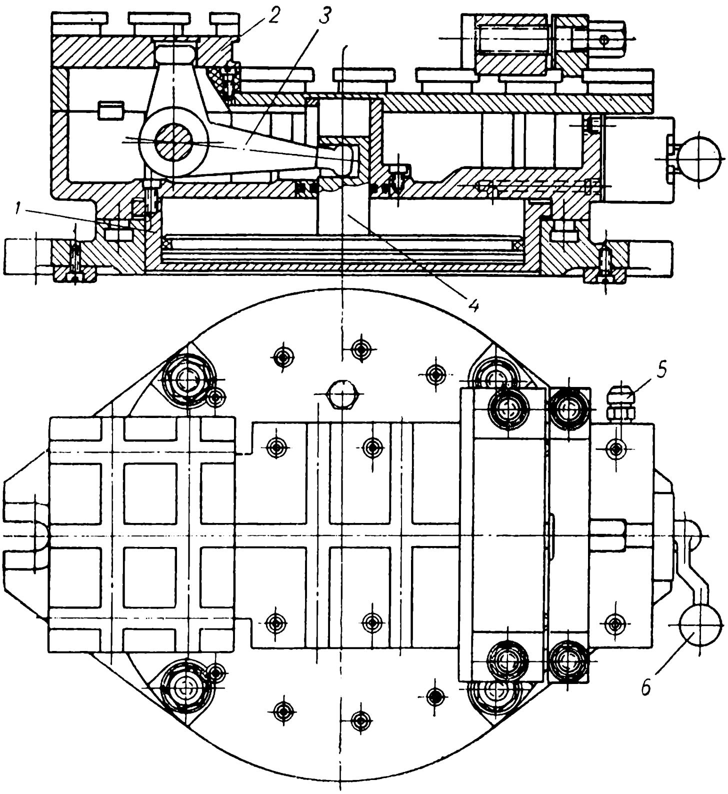


Fig. 41. Pneumatic machine vise

and differs from the latter in that the screw and nut is replaced by an eccentric cam. When the cam is turned, it bears against the strip on the stationary jaw closing the movable jaw and thus clamping the workpiece.

Pneumatic, or air-operated, machine vises (Fig. 41) are more frequently used in lot and mass production. They are used for clamping workpieces, and are fitted with a

pneumatic cylinder (or pneumatic chamber) *1*. Piston rod *4* is connected to unequal-armed angle lever *3* which actuates movable jaw *2*. The vise is closed and opened by turning lever *6*, after which the air from the mains enters pneumatic cylinder *1* through nonreturn valve *5*.

Special devices, called *jigs*, are used on drilling machines to hold the workpieces and to ensure the proper alignment of the tool with the axis of the hole being machined. Jigs are provided with jig bushings to ensure that the hole is machined exactly to the drawing specifications. In the Soviet Union, these bushings are made to standard designs and dimensions. They are classified as: press-fit bushings (Fig. 42*a*) for jigs used in small-lot production for machining holes with a single tool, and slip renewable bushings (Fig. 42*b*), used in large-lot and mass production. Jig bushings are made of grade У10A or grade 20X steel and are heat treated to ensure the required hardness. In jigs, the proper position of the workpiece relative to the tool is ensured by locating elements (stationary stops) which include plain and serrated flat and round-head rest buttons (Fig. 43*a*) and pads. The plain flat-head rest buttons are used for locating flat machined surfaces, while round-head and serrated flat-head rest buttons are used for locating workpieces with an unmachined surface. Locating pads (Fig. 43*b*) are secured in the jig frame by two or three screws. Adjustable locators (Fig. 43*c*) are used if the surface of the workpiece has an allowance which has to be removed during subsequent operations.

The use of jigs eliminates laying out workpieces before machining, eliminates punching centre holes, setting up the workpiece on the machine to the layout lines and clamping it, and also many other operations connected with drilling to layout lines. For this reason, they are widely used in lot and large-scale production.

Jigs are classified as: lay-on, sliding, roll-over and rotary-type jigs, depending on their design.

Lay-on jigs, as their name implies, are usually placed on the workpiece and can be clamped to the latter, or not.

Fig. 44 illustrates a lay-on type, loose plate jig for drilling four holes *6*. The workpiece is placed on the inclined surface of a fixture with its location surface *5* positioned so that the axes of the holes to be drilled are ver-

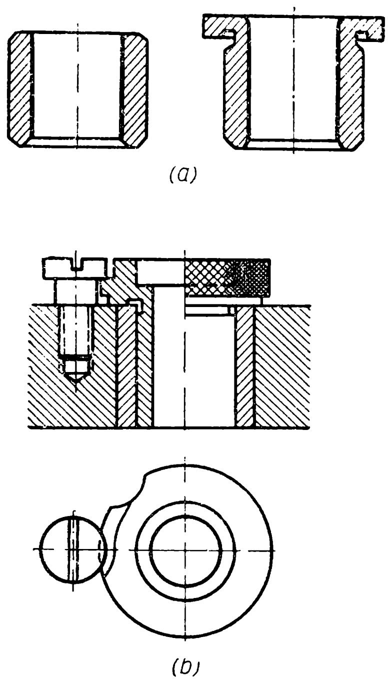


Fig. 42. Jig bushings:

(*a*) press-fit bushing, (*b*) slip renewable bushing

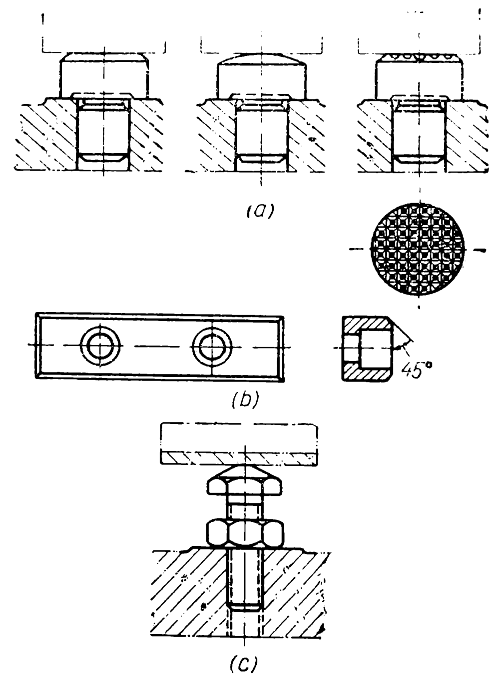


Fig. 43. Locating elements of jigs:

(*a*) rest buttons, (*b*) pads, (*c*) adjustable locators

tical and coincide with the direction of drill feed. After the workpiece has been clamped in this position, jig plate *4* is laid over it. Two locating pins *1* and *2* ensure the proper position of the jig bushings *3* relative to the axes of the holes.

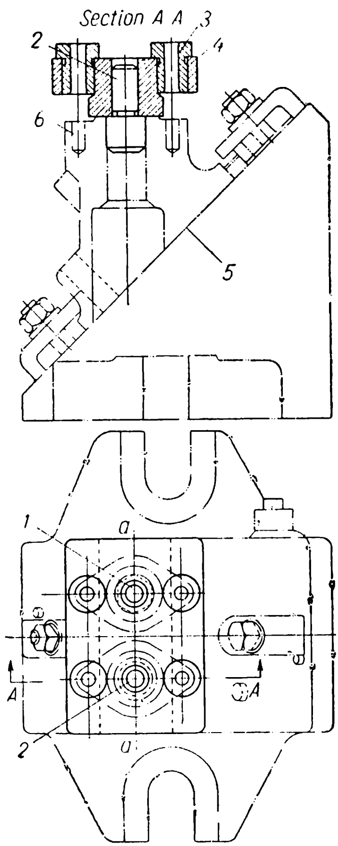


Fig. 44. Lay-on type, loose plate jig

The *sliding jig*, as distinguished from the clamped jig, is not clamped to the drilling machine table, but is repositioned by the drilling machine operator for each new hole. This, of course, tends to make work slower than when using jigs which are clamped to the machine table. These jigs are used when several holes are to be drilled in the same surface of a workpiece on a single-spindle drilling machine. The jig bushings of such jigs may be mounted in a hinged jig plate. Fig. 45*a* illustrates such a jig designed for drilling two holes in the bosses of a workpiece *14* (shown in dot-and-dash lines). Hinged jig plate *4*, carrying two slip renewable bushings *5*, spring clamp *6* and nut *7* for holding plate *4* when the workpiece is being loaded or unloaded, is mounted on pivot *2* on the jig frame *13*. Workpiece *14* is placed on the ground surface of the jig frame; it is located relative to jig bushings *5* with the aid of fixed vee-block *11* and sliding vee-block *15*, linked by pins *3* to screw *16*. Dowel pins *12* serve to fix vee-blocks *11*.

To mount the workpiece *14*, jig plate *4* is swung back to stop *1*. During the drilling operation, plate *4* is locked

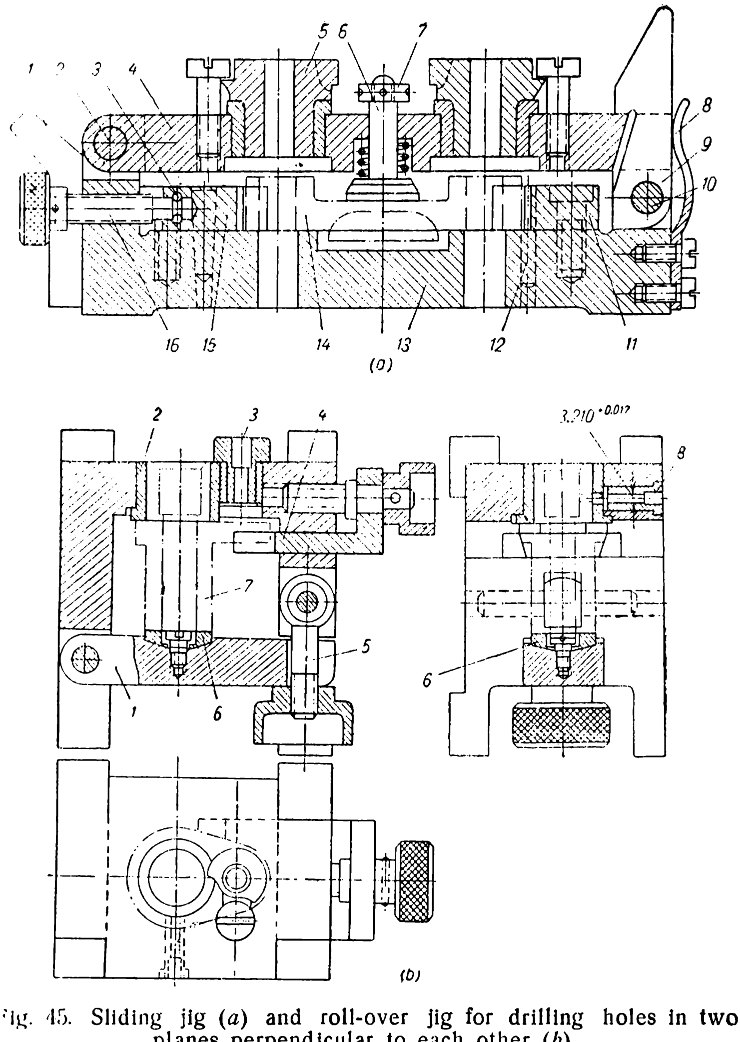


Fig. 45. Sliding jig (*a*) and roll-over jig for drilling holes in two planes perpendicular to each other (*b*)

in position by latch *9*, mounted on pivot *10*, which is held closed by flat spring *8*.

Roll-over jigs are used for drilling holes located in several planes of a workpiece. Fig. 45*b* shows the construction of a roll-over jig. In this jig, two holes in perpendicular planes are to be drilled in workpiece *7*. The workpiece is located by bushing *2* and movable vee-block *4*; it is clamped by hinged bolt *5*, with the aid of hinged plate *1*, which carries a self-aligning pad *6*.

Drilling is effected through jig bushings *3* and *8*; after the hole in one plane has been drilled, the jig is turned over for drilling the hole in the second plane.

Rotary jigs are used mainly for drilling holes in cylindrical surfaces. They are made with vertical, horizontal and inclined axes of rotation. The jig bushings are mounted either in the jig body or on a rotary spindle.

Fig. 46 shows a rotary jig designed for drilling nine holes in a workpiece *4*, which is shown in dot-and-dash lines. The workpiece is mounted on jig spindle *7* and clamped in place by nut *5*, through C-washer *6*. Indexing disk *1* is connected to spindle *7* by key *2*. End play of the spindle is eliminated with the aid of nuts *3*. Fixing member *9* is actuated by spring *8*.

Universal standard (stock) jigs are the most expedient for small-lot and lot production. They can be adapted for machining large quantities of similar-type work of different dimensions. Standard, stock jigs include hand and air-operated pump jigs, which ensure rapid clamping and release of the work and lend themselves to a great variety of changeovers. They can be used for drilling, reaming and tapping holes in levers, covers, bushings, shafts, etc.

Fig. 47 shows an air-operated pump jig and how it can be changed over to suit different workpieces. The work is clamped by the pressure of compressed air which is led through connections *1* into air chamber *2*. Locating elements (rest buttons, pads, etc.) are provided in the jig frame and cover for securing the various setups. Not more than 2 minutes are required to change over the jig for machining a new workpiece.

Universal standard built-up jigs and fixtures have in recent years found wide application in many engineering works for holding workpieces during machining on many types of machine tools, including machining holes on

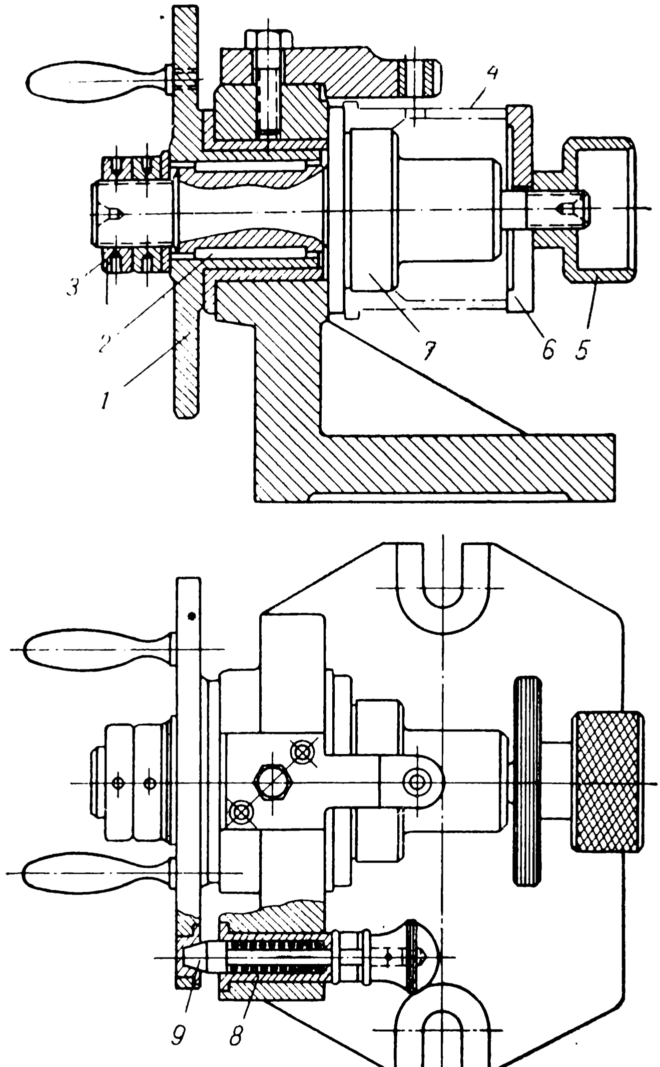


Fig. 46. Rotary jig

drilling machines. These jigs and fixtures are assembled from separate standard elements, kept in stock at the works. After the required lot of work has been machined, the jig or fixture is taken apart and its elements are used

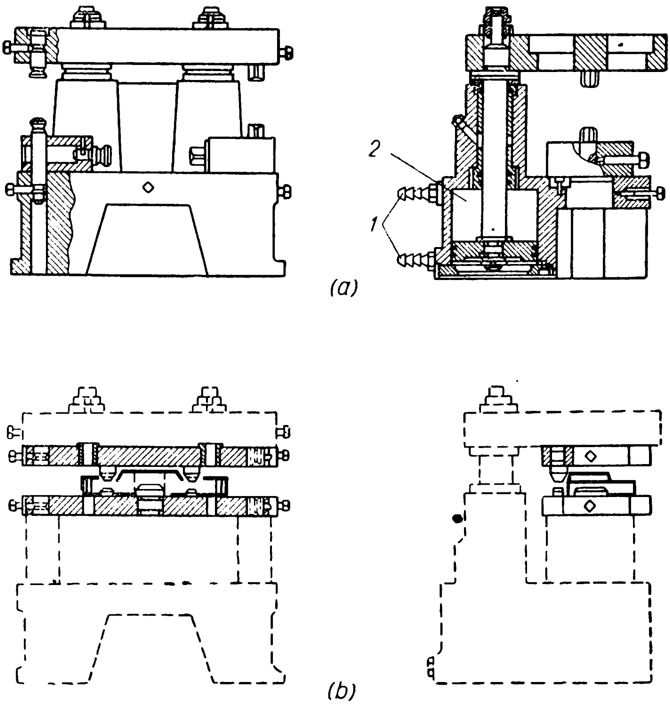


Fig. 47. Air-operated pump jig (*a*) and examples of set-ups (*b*)

for assembling new fixtures or are returned to the tool crib.

Fig. 48 illustrates the assembly of such a fixture for use as a jig for boring two holes with an accurate centre distance O-O_1. The elements of this jig are interchangeable and can be utilized by assembling them in various combinations for drilling many different workpieces.

The use of such stock jigs and fixtures for short-run and piece production saves considerable time and material.

One of the many drilling machine accessories is the *multiple-spindle drilling head*, which is used for simultaneously machining several holes in various workpieces in an upright drilling machine. It considerably increases the efficiency of the drilling machine.

Multiple-spindle drilling heads are available in several designs. Fig. 49 shows an *eight-spindle drilling head*,

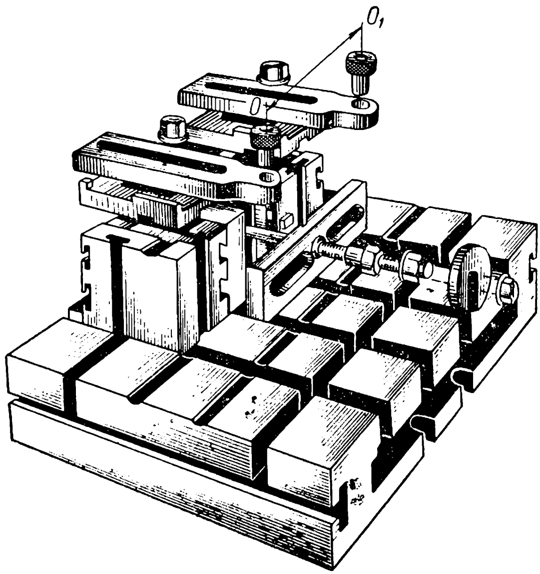


Fig. 48. Universal standard built-up jig

the drilling spindles of which are crank-driven. In crank-driven spindle heads, the drilling spindles can be positioned with minimum possible centre distances between adjacent spindles.

As can be seen from Fig. 49, the spindle head is attached to the drilling machine spindle quill by split collar *1*. Driving spindle *2* carries flywheel *3* with crank pin *4*, which transmits motion to driving disk *7*, linked by cranks *5* to drilling spindles *6*. All the drilling spindles and the crank pins run in ball bearings. The drilling head crank mechanism is balanced by lead-filled holes drilled in the rim of flywheel *3*.

Fig. 50 gives a general view and a longitudinal section of a *universal six-spindle turret drilling head* used for successive drilling of from two to six holes of different diameter and for other hole machining operations. Spindle housing *1*, carrying six drilling spindles *10*, is indexed

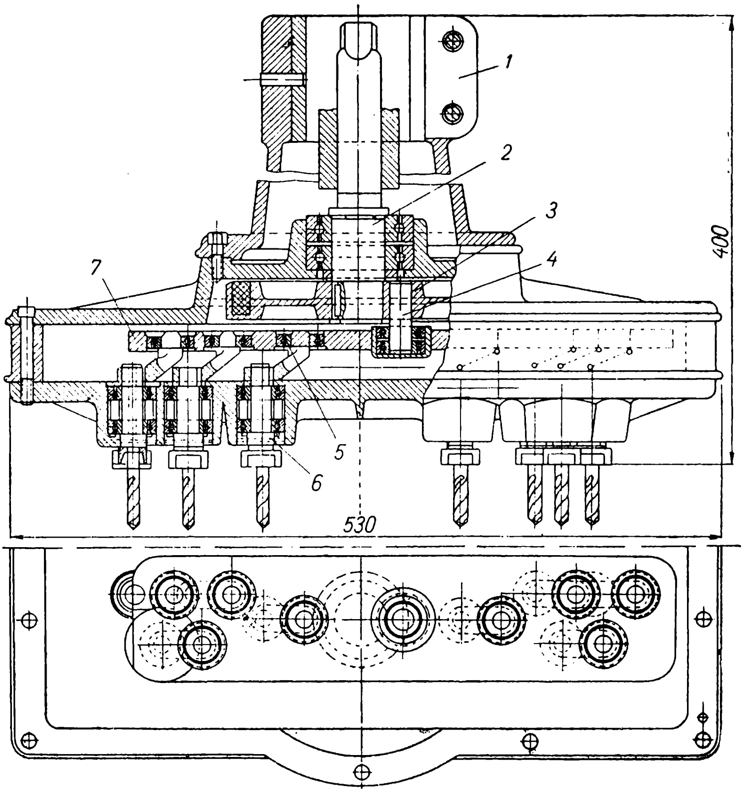


Fig. 49. Eight-spindle drilling head

about shaft *13* in fixed spindle head housing *2*. Each drilling spindle has a jaw or collet chuck on one end for holding the tool, and a three-jaw clutch member *11* at the other. Driving clutch member *12* is rotated by the drilling machine spindle through sleeve *4* and key *5*; clutch member *12* can be moved along sleeve *4* and disengaged from driven clutch member *11* with handle *8*, linked to the

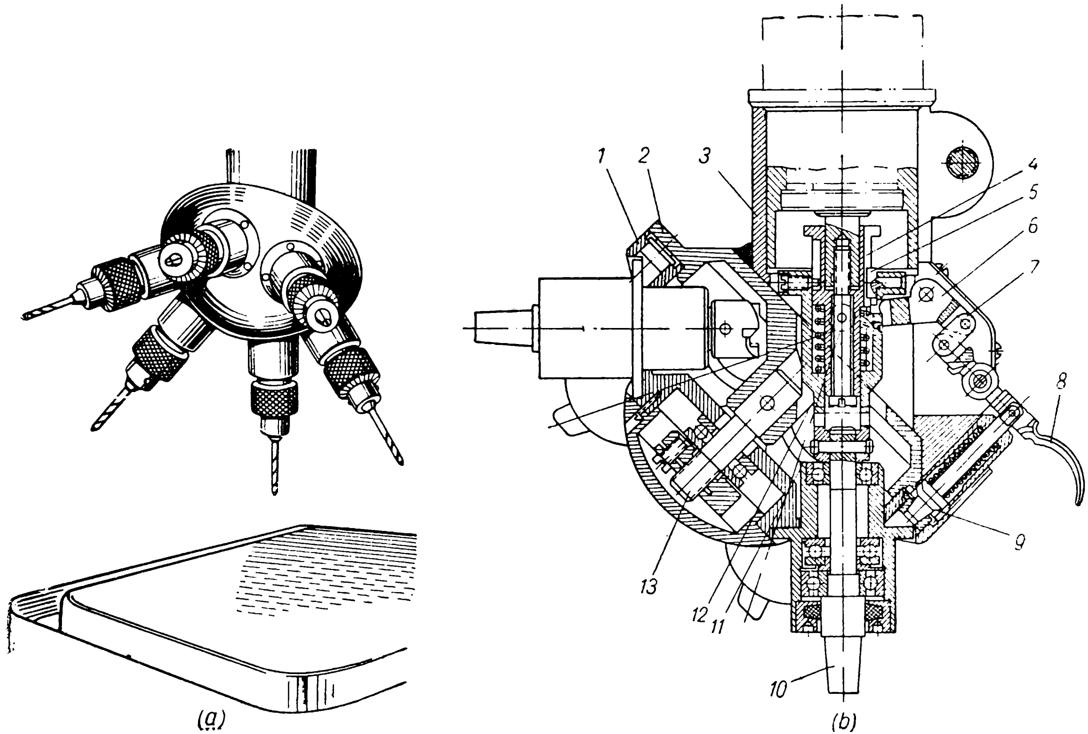


Fig. 50. Universal six-spindle turret drilling head

clutch member by link *7* and lever *6*. Handle *8* at the same time retracts fixing member *9* from indexing spindle housing *1*, thereby permitting any of the six spindles to engage with the driving clutch. The drilling head is clamped on the quill of the drilling machine spindle by collar *3*.

When equipped with a drilling head of the above design, the efficiency of drilling holes from 0.8 to 6 mm diameter can be increased by from 10 to 15 per cent.

5. Measuring Tools and Gauges

In the course of his work, the drilling machine operator has to use various simple measuring tools for measuring and checking the dimensions of work being machined.

Among the most frequently used measuring tools and gauges are: the steel rule, inside calipers, squares, vernier calipers, thread and plug gauges.

The *steel rule* is a rigid strip of steel from 150 to 1,000 mm or more in length and graduated in 1 mm divisions. It is used for the coarse measurement of machined workpieces, distances between hole centres, hole diameters, etc. The accuracy of measurement with a steel rule is up to 0.5 mm.

Inside calipers are used for coarse internal measurements of holes, slots, etc. An inside caliper consists of two curved legs mounted on a pin or rivet around which they can turn freely. For taking measurements with inside calipers, they must be placed inside the hole or slot to be measured and their legs spread apart until their tips contact the internal surface of the hole or slot; the distance between the tips is then measured with a steel rule.

The diameters of precise holes are measured with *inside micrometers* which have an accuracy up to 0.001 mm.

Squares are checking tools, and in drilling operations are used for checking the position of the workpiece relative to the drill. Checking is usually performed visually, by observing the clearance between the blade of the square and the surface of the work; if necessary, this clearance can be measured with a thickness gauge.

Vernier calipers carry a special scale, called the vernier scale, with which measurements can be read to an accuracy of 0.1, 0.05 or 0.02 mm.

Fig. 51 shows a vernier caliper reading to an accuracy of 0.05 mm. It is intended for taking external and internal measurements and also for laying-out operations. The vernier caliper comprises a steel beam *6* graduated in millimetres; it has a pair of jaws *1* and *2* at one end.

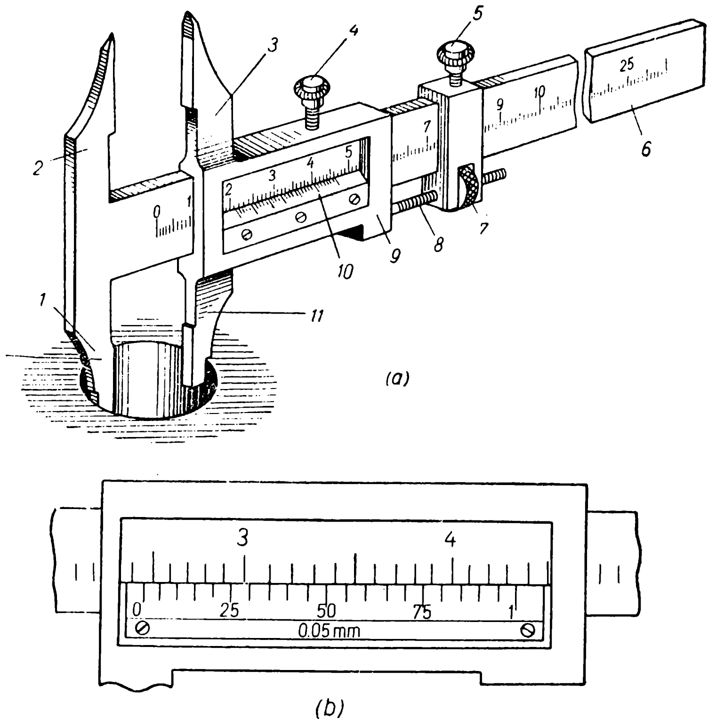


Fig. 51. Vernier calipers (*a*), vernier scale (*b*)

Sliding head *9*, with jaws *11* and *3*, slides along this beam. Vernier scale *10* is secured to this head.

To facilitate accurate measurements, some vernier calipers are equipped with a *micrometric feed* for head *9*; it consists of screw *8*, nut *7* and clamping screw *5*. Clamping screw *4* serves for clamping the head *9* on beam *6*.

Vernier scale *10* is designed for reading fractions of a millimetre on the scale of beam *6*. It is 39 mm long and divided into 20 equal divisions. The number of hundredths of a millimetre is indicated by figures, placed at every 5

divisions. For this reason, the figure 25 is placed opposite the 5th line on the vernier scale, 50—opposite the tenth, and so on. Each division of the vernier scale is equal to $\frac{39}{20}=1.95$ millimetres, i.e., readings can be taken to an accuracy of 0.05 mm.

When taking measurements with the vernier calipers, it is necessary to add to the number of whole millimetres passed by the zero graduation of the vernier scale, the number of hundredths of a millimetre indicated by the vernier scale graduation that coincides with one of the graduations on the scale of beam *6*.

For instance: in Fig. 51*b*, we can see that the zero graduation of the vernier scale has travelled 24 mm on the beam scale, and that its seventh graduation coincides with one of the graduations on the beam scale.

In this case, the graduation will correspond to a length of 0.35 mm (0.05×7) and the measured length will be equal to 24.35 mm, i.e., $24+0.35$ mm$=24.35$ mm. Vernier calipers are available with measuring ranges 0-125, 0-150, 0-200, 0-300, 0-500, 0-600, 0-800, 0-1,000 mm and larger.

The *vernier depth gauge* (Fig. 52) is used for measuring the depth of holes, recesses, grooves and for measuring the height of shoulders.

In principle, it is similar to the vernier caliper.

Beam *4*, graduated in millimetres slides freely in head *8* which has a vernier scale *1* and base *9*. It is secured in the necessary position with the aid of thumb screw *2*. Head *8* is connected to the micrometric feed mechanism which comprises auxiliary slide *5*, screw *7*, nut *6* and thumb screw *3*. The vernier readings are taken in the same way as for vernier calipers.

Vernier depth gauges are made with maximum readings of 150, 200, 300 and 500 mm, with a reading accuracy of 0.1 to 0.02 mm.

Plug and snap gauges are ungraduated measuring tools and are used mainly in large-lot and mass production for checking the accuracy of shafts and holes. They ensure rapid and accurate measuring, or rather checking, of dimensions and are classified as *standard* and *limit* gauges.

Standard gauges are made in sizes equal only to the nominal size of the element of the workpiece being check-

ed. The gauge enters the hole in the workpiece with a greater or smaller degree of tightness.

To-day, limit gauges are mainly used in production. In limit plug gauges, one checking member, or head, is shorter than the other. The longer head is called the GO member, and the shorter head—the NO GO member.

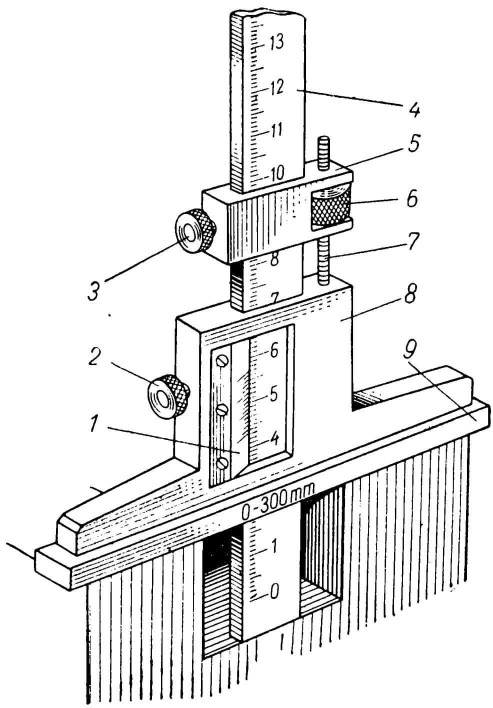


Fig. 52. Vernier depth gauge

Plug gauges (see Fig. 53*a*) are used for checking holes; snap gauges—for checking shafts. The GO member of a plug limit gauge has a diameter equal to the minimum permissible diameter and the diameter of NO GO member is equal to the maximum permissible hole diameter; in limit snap gauges, the opposite is the case. If the NO GO member of the gauge enters the hole or slips over the shaft, the work must be rejected as spoilage. If the GO member of the gauges does not enter the hole or

slip over the shaft, the work is capable of being corrected.

Thread gauges are used for checking external and internal threads. Limit plug thread gauges are used for checking internal threads (see Fig. 53*b*) and limit (GO and NO GO) roll thread gauges for checking external

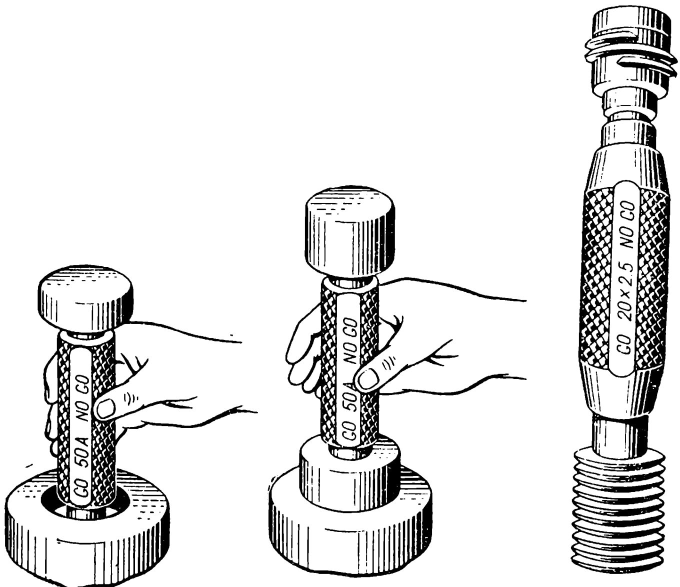


Fig. 53. Plane and thread plug gauges:
(*a*) limit plug gauge, (*b*) limit plug thread gauge

threads. When checking internal threads with a limit plug thread gauge, the GO member should screw into the thread being checked, while the NO GO member should not.

In large-lot and mass production, the geometric tolerances of workpieces are also checked by inspecting devices, such as dial indicators, multidimensional inspection equipment, semiautomatic inspection machines and also devices for the in-process checking of work without stopping the machine.

Chapter VIII

DRILLING MACHINES

1. Drilling Machine Classification

All machine tools, including drilling machines, produced in the Soviet Union are classified by the Experimental Machine Tool Research Institute (ЭНИМС) into groups and types. A number index system has been adopted for identifying each group and type of machine tool.

General-purpose drilling machines belong to the 2nd group of this system and are further subclassified into 6 basic types (Table 9).

Table 9

Drilling Machine Classification

Name of machine tool	Machine group No.	Type of machine	Type index
Drilling	2	Vertical drilling machine	1
		Single-spindle semiautomatic machine	2
		Multiple-spindle semiautomatic machine	3
		Radial drilling machine	5
		Horizontal drilling machine	8
		Other types of drilling machines	9

Further, each type of drilling machine has an index, or model number of its own, consisting of figures indicating its group, type, and drilling capacity. Thus, drilling machine, model 2150, is to be interpreted as: a vertical (upright) type (type index, 1) drilling machine (machine-tool group index 2), with a drilling capacity of 50 mm, i.e., capable of drilling holes up to 50 mm in diameter

(here the last two figures are 5 and 0). The drilling machine, model 2A150, is to be interpreted as a modernized model of the model 2150 upright drilling machine. Here the letter A denotes "modernization".

Drilling machines are subclassified as: general-purpose, specialized and special drilling machines.

General-purpose drilling machines comprise the largest group of drilling machines. All operations entailed in machining holes can be performed on these machines (drilling, tapping, enlarging holes, reaming, etc.). General-purpose drilling machines include *vertical drilling* and *radial drilling machines*.

Vertical drilling machines, in turn, are classified as *single-spindle* and *multiple-spindle, upright, bench* and other types of drilling machines.

Radial drilling machines are built with either only sliding or sliding and swivelling drill heads; they can be *portable* or otherwise, etc.

Specialized drilling machines differ from general-purpose types in that they are intended for performing only a limited number of operations. They are mainly automatic drilling machines arranged for machining two or more holes simultaneously in definite workpieces. Typical of this group are drilling machines that are built up of standard units and power heads.

Specialized drilling machines are equipped with special tooling (fixtures, jigs, special tools, etc.) and are usually employed for large-lot and large-scale line production.

Special drilling machines are employed for performing one or more operations on a definite workpiece, and are not, as a rule, set up for machining other workpieces. Deep-hole drilling machines belong to this group.

2. Vertical Drilling Machines

Vertical drilling machines are so named because their distinguishing feature is the vertical position of the spindle.

One type of vertical drilling machines is the bench-type drill.

Bench-type upright drilling machines are used in piece, lot and even mass production. They are used in the

metal-working industry in machine, tool and other shops for drilling holes with diameters from 0.25 to 12 mm in small workpieces. They are installed on wooden or metal benches to which they are bolted down. Bench-type drill presses are made in various models, but most of them have a common feature—a belt-driven spindle powered by a motor. In addition, the axial feed of the tool is effected by hand from a feed lever, and not by power.

The specifications of bench-type drilling machines, manufactured in the Soviet Union, are given in Table 10.

Table 10

Specifications of Bench-Type Drilling Machines

Model	Drilling capacity, mm	Maximum spindle travel, mm	Distance from spindle to column, mm	Spindle Morse taper No.	Range of spindle speeds, rpm	Spindle feed, mm/rev	Power of motor, kW	Net weight, kg
2A103	3	40	125	1	1,620-15,960	Manual	0.25	40
C-106	3	40	—	—	2,800-16,800		0.18	32
C-25	5	75	120	1	1,600-8,000		0.11	128
2A106	6	75	125	1	1,545-15,000		0.6	82
C-08	8	75	205	2	650-9,000		0.3/0.6	130
HC-12A	12	100	175	2	450-4,500		0.5	100
HC-12Б	12	100	200	1	450-4,430		0.6	180

Let us examine, as an example, the construction and operation of a bench-type drilling machine.

Bench-type drilling machine, model HC-12A, is intended for drilling holes with diameters up to 12 mm in small work. Its specifications are given in Table 10.

It comprises the following main assemblies and parts (Fig. 54): base *9*, column *7*, spindle head *1*, spindle *12*, and electric motor *4*.

Head *1* travels along column *7*, which is supported by bracket *8* bolted down to base *9*. The head is moved along the column by turning lever *11*, and is locked in position at the required height by lever *10*. Electric motor *4* is mounted on the head on motor plate *6*. The motor shaft carries a stepped pulley *3* which is linked to the spindle pulley *2* through a V-belt.

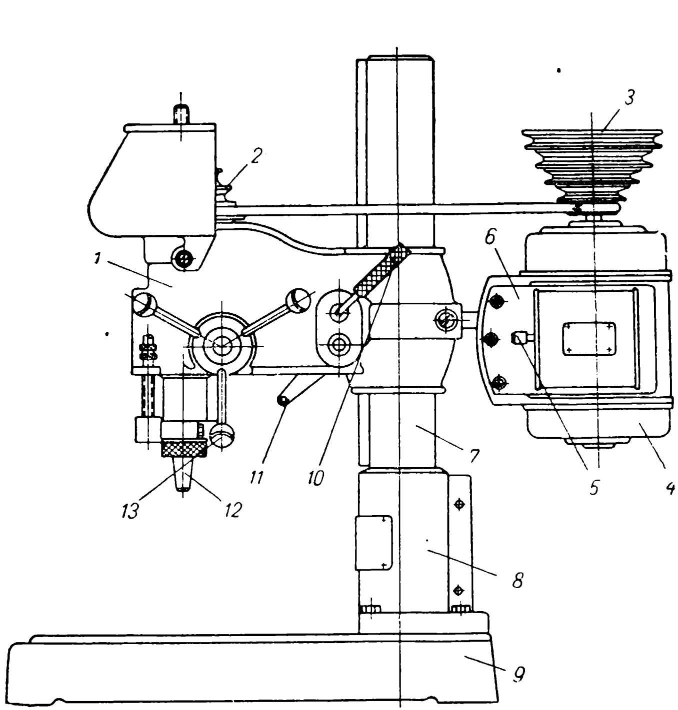


Fig. 54. Bench-type drilling machine, model HC-12A

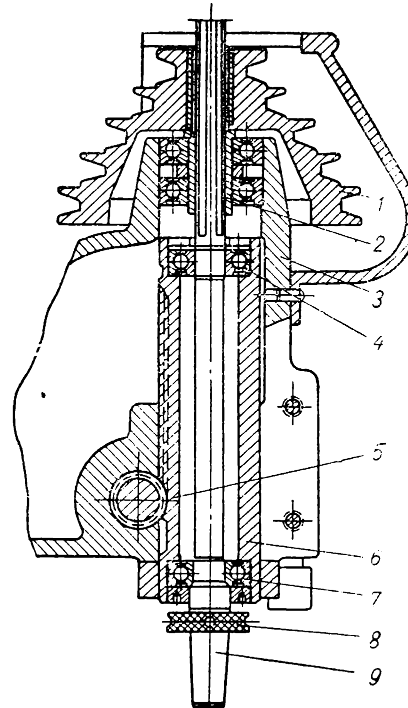


Fig. 55. Spindle assembly of the bench-type drilling machine, model HC-12A

The spindle assembly (Fig. 55) is mounted inside spindle head housing *3*. Spindle *9* is mounted in sleeve or quill *6*, in ball bearings *7* and *4*. It is rotated by pulley *1* through splined joint *2*.

Hand spindle feed is effected by rotating pilot-wheel *13* which turns pinion shaft *5*, meshing with the rack of sleeve *6*, thereby causing the latter to descend as required (see Figs. 54 and 55).

Nut *8* is for removing the drill chuck from the spindle nose. The chuck holds the tool.

A three-phase, a-c induction motor is installed on the machine and controlled by a drum switch. The switch carries the inscriptions: L.H., 0 and R.H. The desired direction of spindle rotation is obtained by turning drum switch lever *5* (Fig. 54) to the corresponding position.

During operation all the friction surfaces and the spindle unit must be lubricated with grade "20" industrial oil at intervals specified in the Service Manual of the machine.

Single-spindle upright machines are used for drilling holes with diameters up to 75 mm. The Soviet Union machine-tool industry produces various models; all are equipped with a speed gearbox and power feed. As a rule, the machine units are assembled on a column and the machines themselves, unlike bench-type drilling machines, are mounted on foundations.

Specifications of upright drilling machines are given in Table 11.

Table 1

Specifications of Vertical Drilling Machines

Model	Drilling capacity, mm	Maximum spindle travel, mm	Distance from spindle to column, mm	Spindle Morse taper No.	Range of spindle speeds, rpm	Spindle feed, mm/rev	Power of motor, kW	Net weight, kg
2118A	18	150	200	2	300-3,100	0.2	1.0	430
2118	18	150	200	2	310-2,975	0.2	1.0	450
2Б118	18	150	200	2	208-2,040	0.1-0.4	1.7	450
2A125	25	175	250	3	97-1,360	0.1-0.81	2.8	925
2A135	35	225	300	4	68-1,100	0.115-1.6	4.5	1.525
2A150	50	300	350	5	32-1,400	0.12-2.64	7.0	2.250
2170	75	500	400	6	22-1,018	0.15-3.2	10.0	4.200

One of the most widely used upright drilling machines is the model 2A135, which we will discuss as an example.

Upright drilling machine, model 2A135 is chiefly intended for repair, tool and production shops of small-lot production plants.

When equipped with special tooling, it can also be used for mass production. This machine is designed for

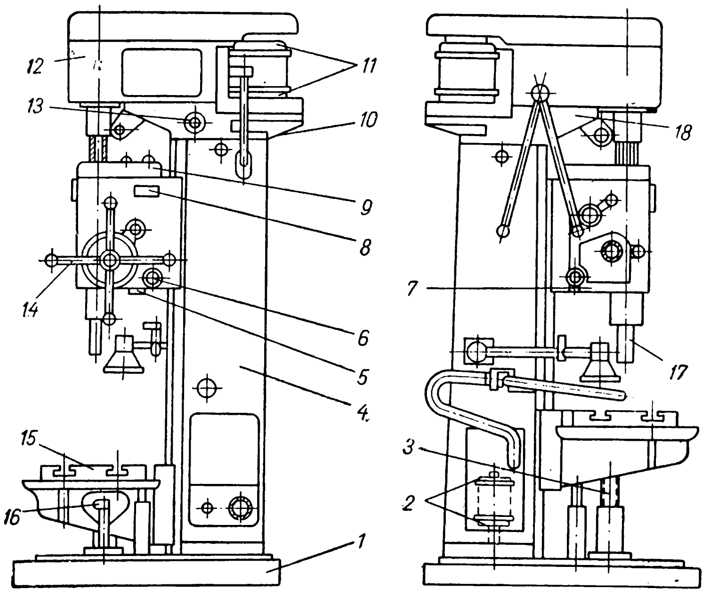


Fig. 56. Upright drilling machine, model 2A135

drilling holes with diameters up to 35 mm. It has a nine-speed gearbox providing spindle speeds from 68 to 1,100 rpm, and a twelve-step feed gearbox for spindle feeds ranging from 0.115 to 1.6 mm/rev. This provides a complete range of standard machining rates for drilling, enlarging, boring, countersinking, reaming and tapping holes with diameters up to 35 mm.

The rigid design of the machine, the strength of its working mechanisms and its amply powered drive permit the efficient use of carbide-tipped tools.

Fig. 56 shows the construction of the model 2A135 upright drilling machine. It consists of base *1*, which also

serves as a coolant tank and to which box column *4* with dove-tailed vertical ways, is bolted. Table *15*, on which the work is clamped, and drill head *7*, travel along the column ways. Speed gearbox housing *12* is mounted on the top of column *4*; its gears are driven by motor *11*, mounted on the side of the speed gearbox. Spindle *17* and the gears of feed gearbox *9*, mounted with the spindle in drill head *7*, are driven directly by the speed gears.

Spindle *17* is fed from feed gearbox *9* through the feed mechanism by power or by hand, from pilot-wheel *14*.

Gearing diagram (Fig. 57). The mechanism of the drilling machine is driven by a 4.5-kW motor running at 1,440 rpm. Rotation is transmitted from the motor shaft to shaft *I* which carries sliding triple cluster-gear *2*; the latter rotates shaft *II* through gears *1*, *3* or *4*, fixed on shaft *II*.

Shaft *II* is linked through gears *5* and *30* to shaft *III*, along which triple cluster-gear *32* slides. The latter transmits rotation through gears *31*, *33* or *34* to shaft *IV* and thence to the spindle.

The feed gears are driven in the following sequence: gear *28*, mounted on the splined section of the spindle, transmits rotation to hollow shaft *VI* through gears *29* and *27*, mounted on shaft *V*, and gear *6*. Hollow shaft *VI* carries triple cluster-gear *26*, rotating freely and continuously meshing with gears *8*, *25* and *24*, mounted on shaft *VII*.

Gears *8*, *21*, *23* and *22* mesh continuously with gear *7* and the triple cluster-gear *9*, which rotate freely on the second hollow shaft *VIII*. Rotation is transmitted from hollow shaft *VIII* through a jaw clutch to worm *14* and worm gear *17*, mounted on the same shaft as gear *15*, which meshes with a rack machined on the spindle sleeve.

Thus, the rotary motion of the feed gear is transformed into the translation, or feed motion, of the spindle.

The spindle can be raised or lowered manually by the pilot wheel mounted on a horizontal shaft which carries gear *16* meshing with internal gear *18*, which limits the depth of drilling.

The drill head can be raised or lowered by turning a crank handle which rotates worm *13*, worm wheel *11* and rack pinion *10*, meshing with rack *12* which is mounted on the column of the machine.

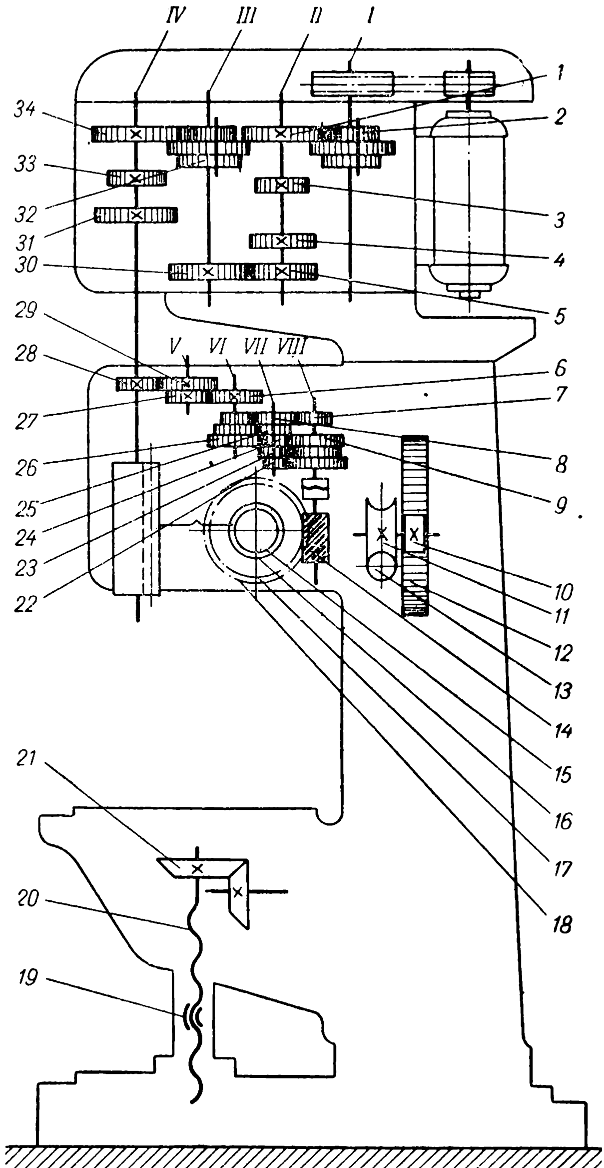


Fig. 57. Gearing diagram of the upright drilling machine, model 2A135

The table can be raised or lowered by turning a crank handle which rotates elevating screw *20* in nut *19* through bevel gearing *21*.

We will now study the construction of the main units of this machine.

The speed gearbox. Spindle rotation and feed are controlled by a special mechanism—the speed gearbox (Fig. 58); the speed gearbox comprises a cast-iron housing *1* in which are located a number of gears, shafts and other parts. The speed gearbox, as has already been mentioned, is driven by a vertically mounted electric motor, the shaft of which carries a pulley *3*. From pulley *3*, rotation is transmitted through V-belts to pulley *2*, which is rigidly mounted on speed gearbox shaft *I*.

The spindle has nine different speeds (68, 100, 140, 185, 275, 400, 530, 750 and 1,100 rpm). These speeds are obtained by shifting the two sliding triple cluster-gears *4* and *8* along splined shafts *I* and *III*, when they engage successively with gears *5, 6, 7, 9, 10* and *11* on shafts *II* and *IV*.

The sliding cluster-gears are shifted by forks actuated by levers located on the left wall of the speed gearbox (these are not shown in Fig. 58). Speed gearbox shaft *IV* is a hollow sleeve, with a spline hole by means of which the rotation is transmitted to the spindle. All the speed gearbox shafts run in antifriction ball bearings which can be readily adjusted by screws in the covers of the gearbox.

The feed gearbox (Fig. 59) is located in the feed mechanism housing. It provides twelve power feeds ranging from 0.115 to 1.6 mm per revolution of the spindle.

Rotation is transmitted from the spindle through a set of gears *1*, *2* and *3* to double gear cone *4* with two sliding keys *5* actuated by levers *7* and *8*, located on the left-hand cover of the drill head. The end of shaft *6* mounts a jaw clutch member (not shown in Fig. 59), which engages a similar member mounted on the worm shaft of the speed mechanism.

The spindle feed mechanism. The housing of the feed mechanism (Fig. 60) is an iron casting in which are mounted the feed mechanism, spindle and feed gearbox mechanism.

The feed mechanism is driven from the feed gearbox through clutch *12*, which is designed for disengaging the

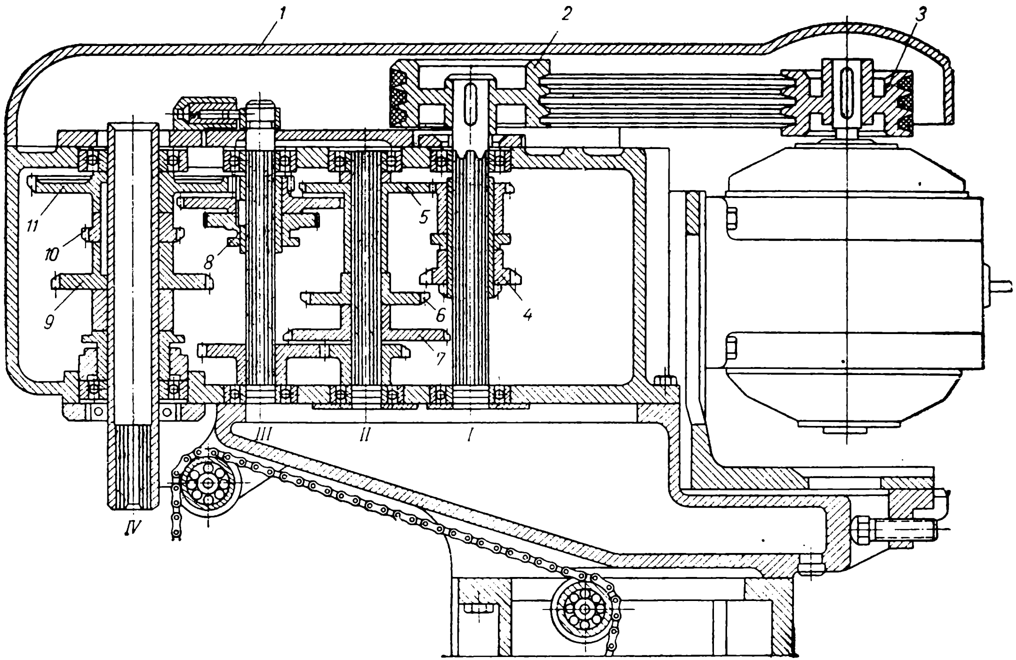


Fig. 58. Speed gearbox of the upright drilling machine, model 2A135

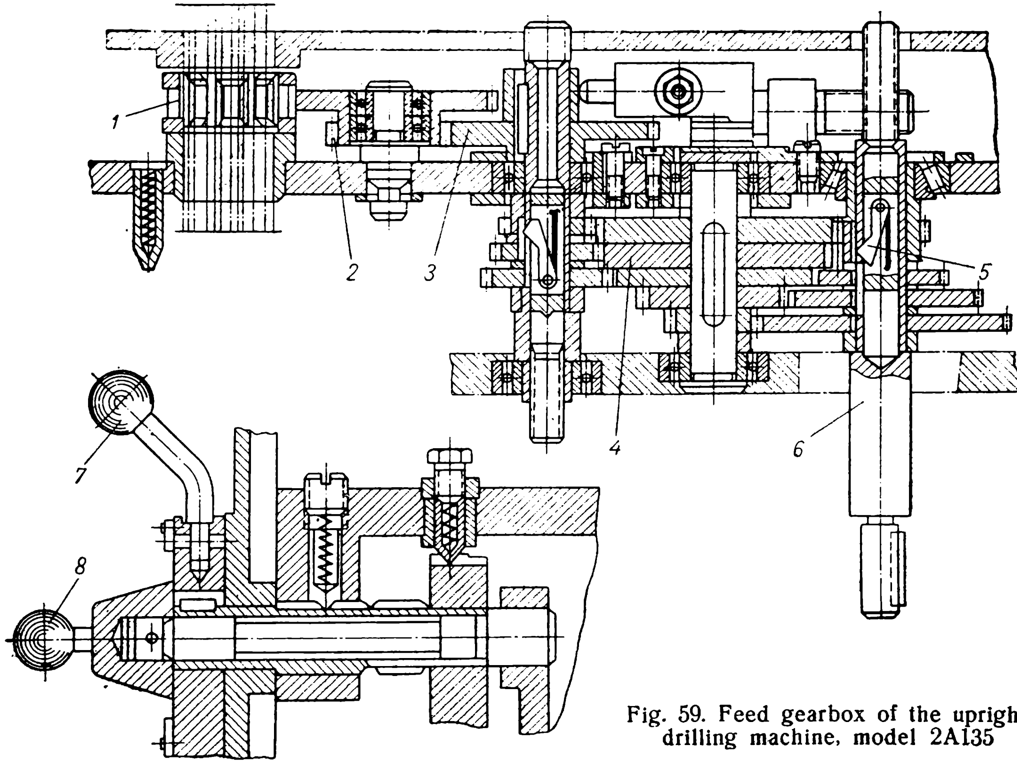


Fig. 59. Feed gearbox of the upright drilling machine, model 2A135

power feed by means of cam *15*, mounted on dial *16*, and for preventing breakage of the parts of the feed mechanism and overloading the mechanisms of the drilling machine.

The power feed can be disengaged at any time by turning pilot-wheel *1* in the reverse direction, i.e., away from the operator.

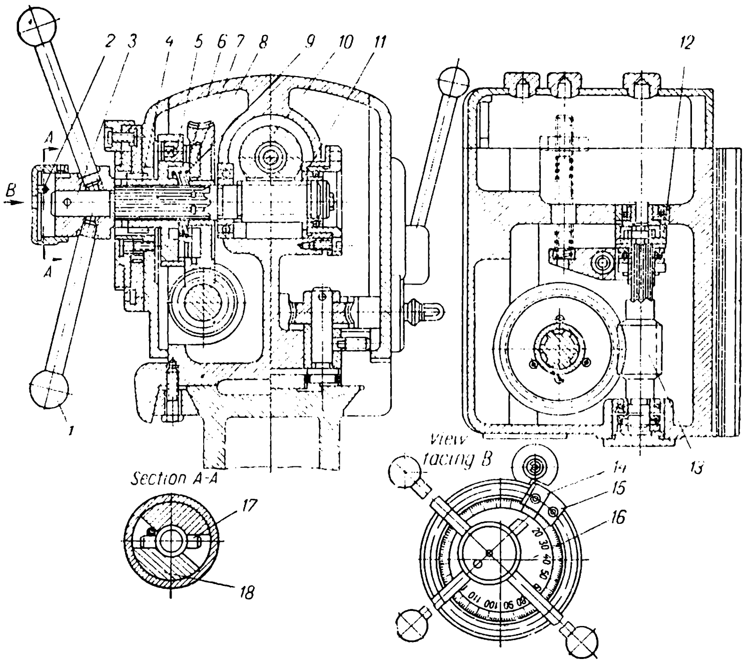


Fig. 60. Feed mechanism of the upright drilling machine, model 2A135

The principle of operation of the feed mechanism is as follows: when the pilot-wheel is rotated towards the operator, clutch *18*, linked to the pilot-wheel shaft, turns through an angle of 20° relative to the shaft; this angle is limited by a slot on the clutch, and by pin *17*. The jaws of clutch *18* then move sleeve *4* axially and, when its ends contact the teeth of the sleeve, lock it in position.

The sleeve carries a double-action ratchet disk *6* to which it is connected by spring-loaded pawls *5*. When the

sleeve is shifted, disk *6* engages the teeth of second disk *7*, attached to worm gear *8*. Thus, as the jaws of clutch *18* and the teeth of sleeve *4* are in complete mesh, the rotation of worm wheel *8* is transmitted to shaft *3*. On further rotation of pilot-wheel *1* when the feed is engaged, spring-loaded pawls *5* located in sleeve *4*, will slide over the teeth on the inner side of disk *6*, thereby engaging the power feed.

The power feed is disengaged by hand by rotating pilot-wheel *1* in the reverse direction through an angle of 20° relative to the axis of the shaft *3*, when the jaw of clutch *18* enters the recess of sleeve *4*. Due to the axial force resulting from the angles of inclination of the jaws of disks *6* and *7*, and special spring *9*, the sleeve is shifted to the right, disengaging the disks and thereby disengaging the power feed.

The feed mechanism provides for direct manual feed of the spindle with the aid of the pilot-wheel, through rack pinion *11* and spindle sleeve *10*. For this, the power feed is disengaged by pilot-wheel *1* and then the ring in the centre of the pilot-wheel is pushed along shaft *3*, away from the operator. This causes pin *2* to lock pin *17*, and the rotation of the pilot-wheel will be transmitted directly to horizontal shaft *3*.

When the power feed is engaged by cam *14* (through clutch *12* on worm *13*), horizontal shaft *3* is not disengaged, and the rotating tool will not be withdrawn from the hole and will finish the surface being machined without feed, which is especially important for facing operations. The spindle is provided with an electric reversing device which can be controlled automatically or by hand; this device allows the drilling machine to be used for tapping operations with manual advance and withdrawal of the tap.

The *spindle* transmits rotation to the cutting tool, and therefore the machining accuracy depends to a great degree on the precision with which the spindle is manufactured and assembled.

The spindle *5* (Fig. 61) consists of a shaft, the nose end of which is of greater diameter than the rest of the shaft, and has a tapered bore *1* for holding the tool. The upper end of the shaft has splines which mesh with the spline hole of bushing *7*, in which the spindle is traversed

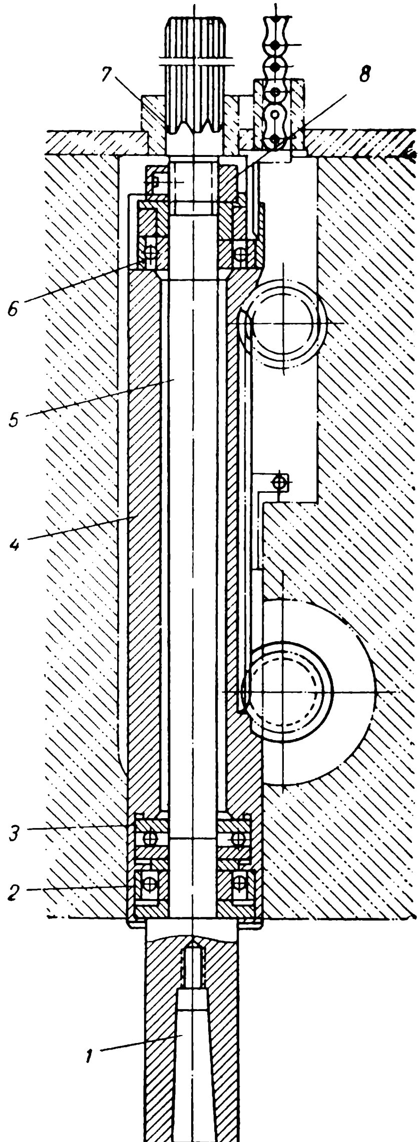


Fig. 61. Spindle of the upright drilling machine, model 2A135

freely by the rack machined on the surface of sleeve *4*. Together with ball bearings *2*, *3* and *6*, the spindle is mounted in sleeve *4*, in which it receives both rotary and axial movements and is balanced by a counterweight located in the column of the drilling machine. The axial thrust of the feed is taken up by ball thrust bearing *3*.

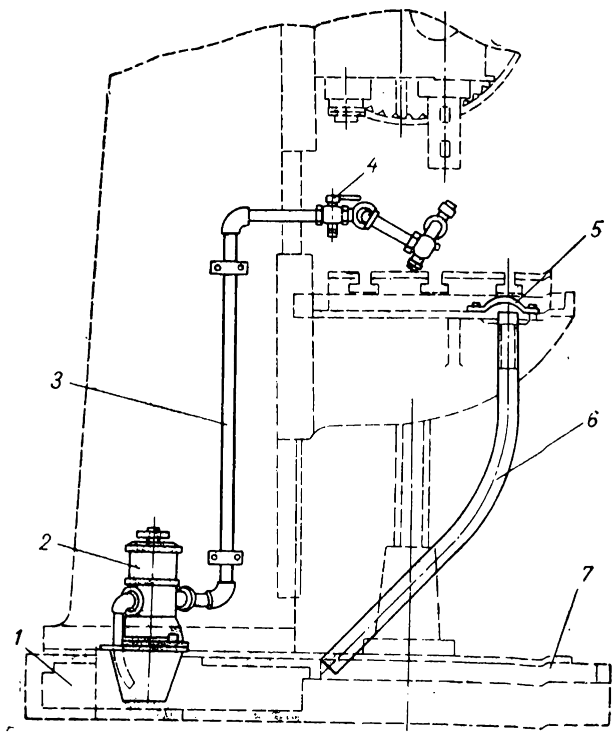


Fig. 62. Coolant system of the upright drilling machine, model 2A135

The bearings are adjusted by drawing up nut *8* through the opening located in front of the drill head.

The coolant system. Electric coolant pump *2* (Fig. 62), mounted on base *7*, delivers the coolant to the tool during operation.

The pump forces coolant from reservoir *1*, built into the base. The reservoir is of labyrinth design, for filtering

the cutting fluid. The cutting fluid is fed to the tool through a flexible pipeline *3*, with a flow-regulating cock *4*.

Used cutting fluid, flowing back to the reservoir along pipeline *6*, is cleansed from chips as it passes through screen *5* in the table and a grate in the foundation plate, whence it returns to the electric coolant pump. The pump sump in the base should be cleaned from dirt at least once a month.

Lubricating the machine in the process of operation will ensure uninterrupted operation of its mechanisms and will increase the life of its rubbing parts. Special devices are installed on the machine for supplying oil to its working parts.

Lubricating oil must be clean, acid-free and should contain no moisture or hard particles.

Grade "3" spindle oil, grade "Л" and grade "C" machine oils are recommended for lubricating this machine.

The speed gearbox mechanisms are lubricated with the aid of a special pump which delivers the oil from the oil tank to the gearbox. When the machine is in operation, the oil delivered by the pump is splashed by gears rotating at high speed and lubricates all the working surfaces of the mechanism of gearbox *12* (see Fig. 56).

The gears of the feed gearbox and the feed mechanism *7* are lubricated with the aid of a pump installed in the feed gearbox and which delivers the oil from the lower cavity in the spindle head.

The spindle bearings are lubricated by a wick from a recess in the feed gearbox. The electric motor bearings, electric coolant pump bearings, the table elevating screw and shaft must also be lubricated.

The column ways and the splines of the spindle must be lubricated every day.

The oil in the tank should be changed after every six months of operation of the machine. Waste oil is drained off through drainholes *5* and *10* in the speed gearbox and the bracket.

When changing the oil, the mechanism should be washed with kerosene; before refilling the oil tank, the oil must be filtered.

The oil level is checked through the oil-level gauges *6*, *8* and *13* located in the speed gearbox housing, spindle head and feed gearbox housing.

Operating and servicing the machine. Before commencing work on the drilling machine, it must be set up.

This consists in bringing the table and spindle head to the required working position, and in setting the spindle speed and feed.

The depth of drilling is set on the dial as follows (see Fig. 60). Turning pilot-wheel *1* toward the operator, the spindle is lowered until it contacts the workpiece. Then the screws of feed disengaging cam *15* and cam *14* are loosened, cam *15* is shifted until it coincides with the dial graduation corresponding to the depth of drilling, and the screws are retightened. The graduation on the dial will then correspond to the full depth of drilling (including the length of the drill point).

Cam *14* is designed for adjusting the automatic spindle reversing device when using the machine for tapping operations.

The Service Manual, its purpose and contents. Every machine tool is furnished with a Service Manual which gives the name of the manufacturing plant, the model of the machine and its chief specifications (drilling capacity, speed of electric motor, number and range of spindle feeds, etc.).

The manual also gives the gearing diagram of the machine, the construction of its separate units, describes the lubricating and coolant systems, and also gives the electrical circuit diagram of the machine. In addition, it gives a list and drawings of the parts subject to wear and spare parts of the machine.

The Service Manual is the main document for setting up, operating and repairing the machine.

3. Radial Drilling Machines

Radial drilling machines are designed for drilling several holes that may be located at considerable distances from one another in heavy and large workpieces. As distinguished from ordinary drilling machines, they can drill holes at any point of the surface of the workpiece by shifting the drilling spindle only, without changing the position of the workpiece.

On ordinary drilling machines, it is rather difficult at times to move heavy work rapidly towards the machine spindle without impairing its setup.

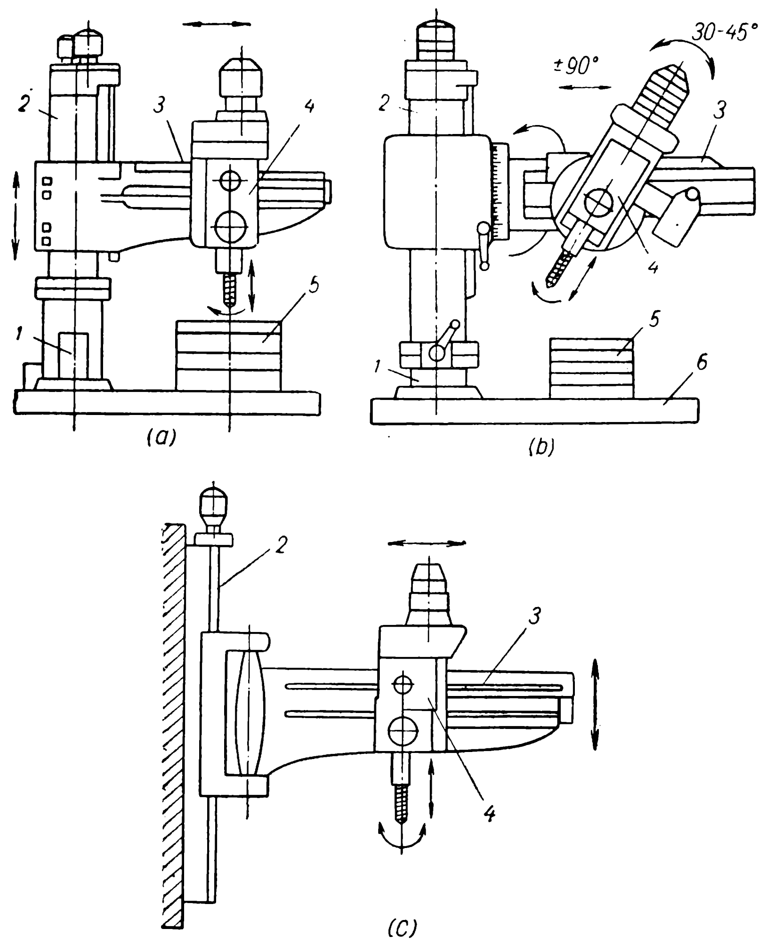


Fig. 63. Radial drilling machines

Fig. 63 gives the more typical designs of radial drilling machines. The chief units of these machines are: the pedestal *1* (together with the plate *6* and box table *5*); column *2*, bolted to the pedestal; radial arm *3* which is fitted over the column and can be raised or lowered on the column or swung about its axis. Drill head *4* is mounted on arm *3* and can be traversed along the latter, on ways.

The radial drilling machine shown in Fig. 63*a* is used in toolrooms, machine and assembly shops in the metal-working industry for various kinds of work; the machine shown in Fig. 63*b* is used in the ship-building industry and in large engineering plants manufacturing powerful engines. The spindles of these machines can be inclined and the drill head *6* and radial arm *3* can be swivelled.

The principle of a wall-type radial drilling machine used in the ship-building industry and in steel structure plants, is shown in Fig. 63*c*.

All radial drilling machines work on the same basic principle. We will take radial drilling machine, model 2A53, as an example. This machine is widely used in the engineering industries and also in auxiliary maintenance shops for machining holes up to 35 mm diameter. It is used for drilling, enlarging, counterboring, reaming, facing, countersinking, tapping and other operations.

The *gearing diagram* of this machine is given in Fig. 64. Rotation is transmitted by an electric motor with two speeds, 1,420 and 2,840 rpm, from shaft *I* to gearbox shaft *II* through a pair of gears *1* and *2*.

Shaft *II* carries upper and lower friction clutches *4* and *5*; when successively engaged, they transmit rotation to shaft *IV*—upper clutch *4* through gears *3* and *34*, and lower clutch *5* through gears *6*, *7* and *8*. Idle gear *7* is mounted on shaft *III* for reversing the spindle when the clutches are shifted.

A double cluster-gear which can be shifted to three different positions, slides along spindle sleeve *VI*.

In its upper position, the cluster-gear transmits rotation to the spindle through gears *34* and *33*; in its central position—through gears *31* and *32*, while in its lower position gear *32* meshes with gear *30*, and the spindle is driven from shaft *IV* through shaft *V* by means of gears *9, 29, 30* and *32*.

The feedbox mechanism is driven from the spindle through a constant-ratio reducing gear (shafts *VII* and *VIII*) and gears *28, 10, 27, 11, 12* and *26*. Gear *26* is keyed to shaft *IX*, which carries a sliding double cluster-gear which transmits two speeds to shaft *X* through gears *25* and *13*, or through gears *23* and *22*. A quadruple cluster-gear, sliding along shaft *XI*, transmits eight speeds to this shaft through gears *22, 15, 21, 16, 20, 17, 24* and

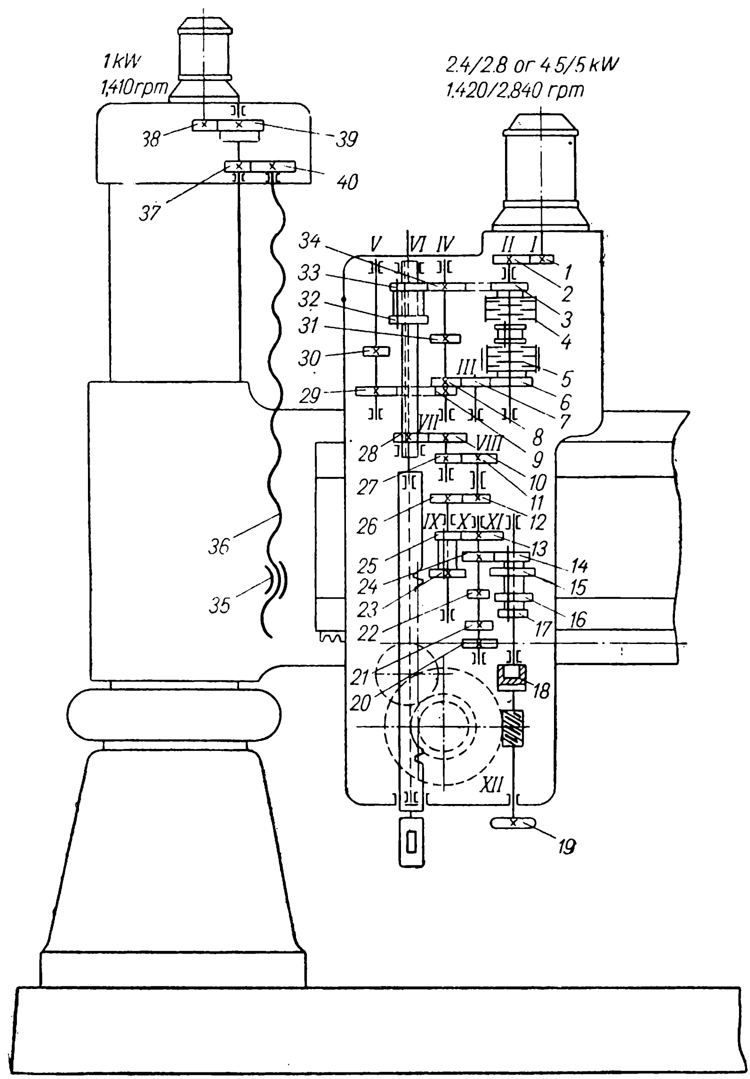


Fig. 64. Gearing diagram of the radial drilling machine, model 2A53

14. When jaw clutch *18* is disengaged, rotation is transmitted through shaft *XII* from the feed gearbox to the feed mechanism.

When clutch *18* is engaged, the spindle can be fed by hand with the aid of handwheel *19*.

The arm elevating mechanism is driven by a separate electric motor, with a speed of 1,410 rpm, from which rotation is transmitted to elevating screw *36* through gears *38, 39, 37* and *40*. The screw, rotating in nut *35* fastened in the arm, raises and lowers the latter.

The Soviet machine-tool industry produces a whole series of radial drilling machines: models 2A53, 2Б58, 2Д58, and others.

4. Multiple-Spindle Drilling Machines

Multiple-spindle drilling machines are used mainly in lot production, for machining workpieces requiring simultaneous drilling, reaming, and tapping of a large number of holes in different planes of the workpiece.

A single-spindle drilling machine would not be economical for these purposes, as not only would a considerably larger number of machines and operators be required but the machining cycle would be longer.

Multiple-spindle drilling machines are available with fixed and adjustable spindles, known as gang and adjustable-centres multiple-spindle drilling machines.

Gang, or straight-line, type drilling machines usually carry from two to six spindle heads, located in a row with fixed distances between their centres (Fig. 65).

By passing the workpiece from spindle to spindle many different hole machining operations can be performed consecutively on this machine (drilling, enlarging, reaming, etc.).

Each spindle is driven by its own electric motor.

Machines of this type are general-purpose machines and can be used for machining holes in many kinds of workpieces.

Adjustable-centres multiple-spindle vertical drilling machines (Fig. 66) differ from gang-type drilling machines in that they have a common drive for all spindles. All the main units are mounted on base *1*. The main

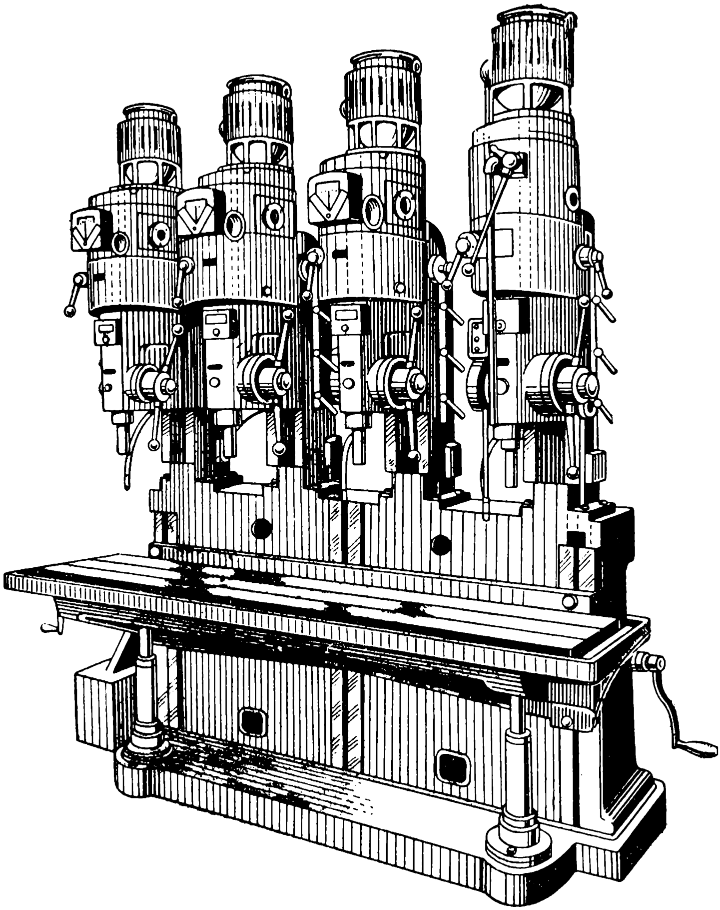


Fig. 65. Gang, or straight-line, type drilling machine

spindle *6* is driven by electric motor *8* through gearbox *7*. In its turn main spindle *6* drives the working spindles *4*, located in the multiple-spindle drill head *5*, through a group of transmission gears. The drill head, fitted with a hydraulic or mechanical feed, travels up and down the ways of the column. In this case, the working stroke (down) of the spindles is slow, and the return one (up) is

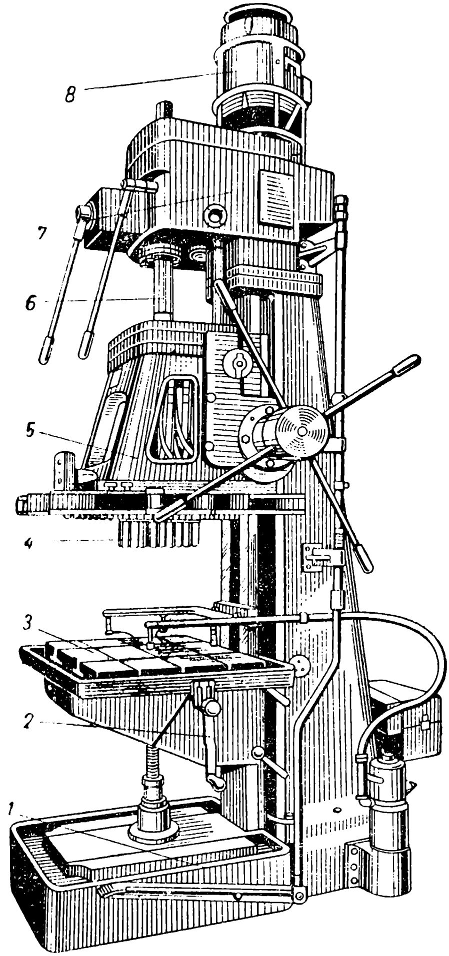


Fig. 66. Adjustable-centres multiple-spindle vertical drilling machine

rapid. Table *3* can also be raised and lowered along the ways of the column by crank handle *2*. The spindles can be adjusted in the spindle head for drilling holes of varying diameters at random locations on the workpiece,

5. Unit-Type Multiple-Spindle Drilling Machines

Unit-type multiple-spindle drilling machines are designed for simultaneously performing many different hole machining operations (drilling, boring, tapping, etc.). These machines are usually assembled from standard units. They come in horizontal, inclined or vertical spindle-head types, or in types combining all three kinds of spindle heads. The latter are also called way-drilling machines.

Fig. 67 illustrates three unit-type multiple-spindle drilling machines. Electric motors *1* transmit rotation through power units *2* and spindle boxes *3* to a group of working spindles *4* carrying various tools. These units are assembled on columns or sub-bases *5* which, in turn, are bolted to tables *6*. Work clamping devices *7* are mounted on the latter.

Unit-type multiple-spindle drilling machines are most frequently used for the mechanization and automation of production processes.

Fig. 68 shows a special six-station centre-column unit-type multiple-spindle drilling machine for drilling, counterboring, countersinking, reaming, spotfacing and tapping automobile engine cylinder blocks.

It is equipped with more than 150 spindles, and has an output of about 60 blocks per hour.

The holes in the block are machined through jig plates *2*, travelling together with the spindle heads; fixtures for holding the block are clamped on table *1*, which rotates around central column 7 and is supported by a large ball bearing approximately 2,800 mm in diameter.

On completion of each working cycle, the spindle heads are returned to their initial positions and the table is indexed by a special electric motor, with the aid of an indexing mechanism.

The central column has six sides, on five of which travel vertical multiple-spindle heads *6*; the loading station is located opposite the sixth side.

Horizontal spindle heads *5* travel along sub-bases *4*, bolted to the central base *3*.

Each tapping spindle rotates in a pilot bushing located on the jig plate, and which is threaded with a pitch corresponding to that of the hole to be tapped.

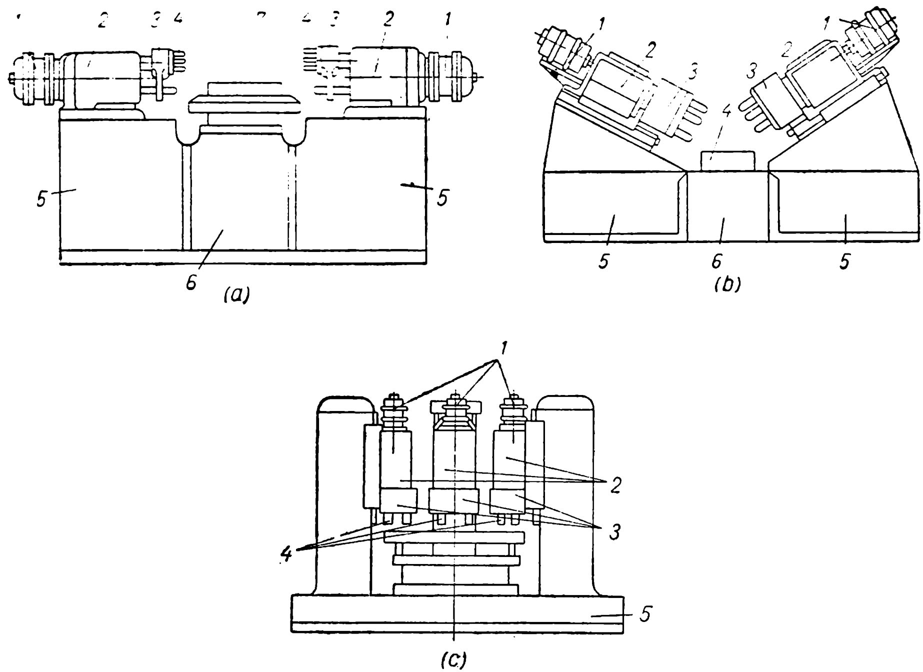


Fig. 67. Unit-type multiple-spindle drilling machine:
(*a*) with horizontal spindle heads, (*b*) with inclined spindle heads, (*c*) with vertical spindle heads

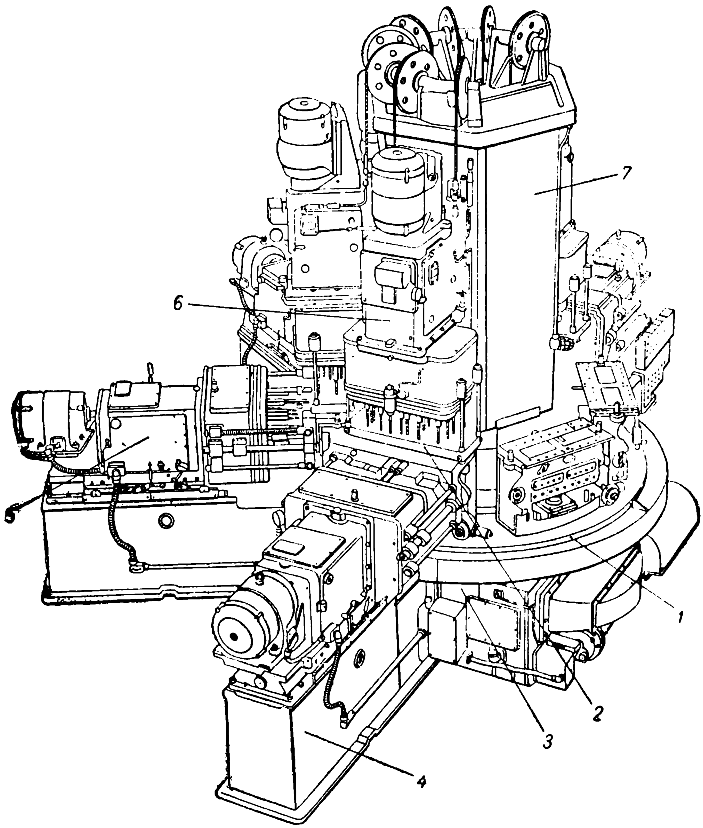


Fig. 68. Six-station centre-column unit-type drilling machine

Thus, although the multiple-spindle head has only one feed, threads of different pitch may be tapped in the holes of the cylinder block.

Chapter IX

DRILLING MACHINE OPERATION

1. Applications of Drilling Machines

The scope of work which drilling machines can handle is not limited to the operation of drilling holes. Further machining of holes, especially with general-purpose drilling machines, and a number of other operations not connected with the direct machining of holes can be performed on these machines.

The following operations can be performed on modern drilling machines.

Drilling through and blind holes (Fig. 69*a*).

Enlarging small-diameter holes to larger diameters (Fig. 69*b*),

Core drilling, performed for the same purpose as enlarging. Higher machining accuracy and surface finish can be obtained by this operation. Moreover, it is much more efficient than boring large diameter holes with a single drill (Fig. 69*c*).

Boring previously drilled holes is performed with a stub arbour and boring tool on drilling machines for machining holes located on a workpiece to precise coordinates. Rough and finish boring of holes are distinguished; rough boring is chiefly performed for removing the surface layer in forged or cast holes; while finish boring produces holes of correct shape, and specified accuracy and surface finish (Fig. 69*d*).

Counterboring and countersinking, for obtaining cylindrical and tapered recesses in drilled holes for the heads of screws, bolts and other parts (Fig. 69*e*).

Reaming cylindrical and tapered holes, for obtaining the required accuracy and surface finish. Reaming may be single-pass (rough), double-pass (finish) or fine (preci-

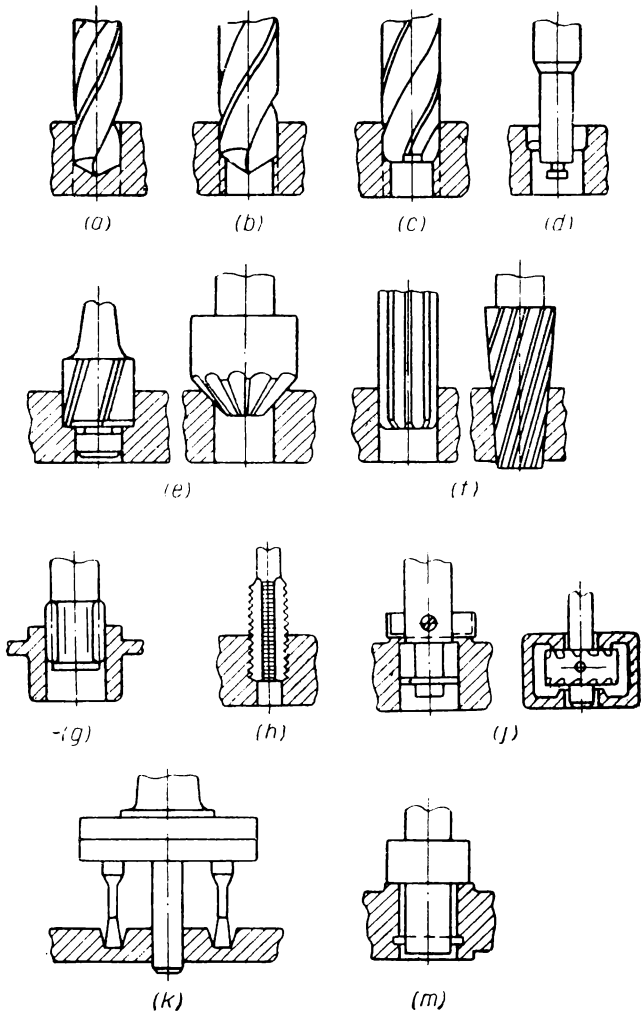


Fig. 69. Operations performed on drilling machines:

(*a*) drilling, (*b*) enlarging, (*c*) core drilling, (*d*) boring, (*e*) counterboring and countersinking, (*f*) reaming, (*g*) burnishing, (*h*) tapping, (*j*) spotfacing, (*k*) sheet metal trepanning, (*m*) recessing

sion), depending on the required accuracy and surface finish (Fig. 69*f*).

Burnishing or *expanding*, for compressing (flattening) the ridges on the hole surface after final reaming, in workpieces of aluminium, duralumin, electron, magnesium and other light alloys. Burnishing is performed with special roller mandrels as very small allowances are left for this operation (0.005-0.01 mm), depending on the hole diameter (Fig. 69*g*).

Tapping with taps on drilling machines equipped with spindle reversing devices (Fig. 69*h*).

Facing external and internal bosses and lugs (spotfacing) to obtain flat and smooth surfaces, perpendicular to the hole axis (Fig. 69*j*).

Sheet-metal trepanning (producing a hole by cutting the circumference directly) with tool bits (one, two or four) mounted in a special arbour with a pilot. Trepanning large-diameter holes in sheet metal (especially in thin sheets) is more economical than drilling, since a machine tool of smaller power may be used for this purpose (Fig. 69*k*).

Machining internal recesses of various shapes with special tools which convert the axial feed of the spindle to a radial feed of the recessing tool (Fig. 69*m*).

The main categories of work given above do not exhaust all the processing capacities of drilling machines, which can also be used for shaping ordinary rivet heads, expanding hollow rivets, machining polygonal holes, etc. But since a 1st or 2nd category drilling machine operators must be able to perform only a limited number of operations, we shall discuss in detail only drilling, enlarging, reaming, counterboring, countersinking and tapping operations.

2. Drilling

Drilling as an independent (final) operation is performed if the specified machining accuracy need not exceed the 4th-5th accuracy grade and the surface finish—the 4th class. Depending on the accuracy grade and the lot size, holes are drilled either after being layed out or in jigs. In the first case the machining accuracy will not be better than the 5th grade and in the second—the 4th grade.

Two main types of holes are met with in parts of machines and mechanisms: through holes, passing right through the body (the entire thickness) of the part, and blind holes which are drilled only to a certain depth.

The procedure for drilling through holes differs somewhat from that for drilling blind holes.

In drilling *through holes*, as the drill approaches the other end of the hole, the resistance of the material of the work considerably diminishes. If the feed is not reduced at this time, the drill will descend sharply and, biting into a thick layer of material, may break as a result of binding. To avoid this, the power feed should be disengaged near the end of the hole, and the hole completed with slow manual feed.

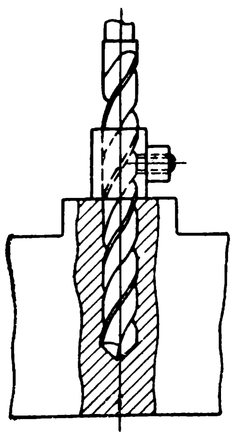


Fig. 70. Stop on drill to limit the depth of drilling

To drill a *blind hole* to a specified depth as rapidly as possible, on a machine not equipped with an automatic feed disengaging device, a stop in the shape of a bushing should be fastened to the drill (Fig. 70).

Another method is to mark the drilling depth on the drill with chalk, and to feed the spindle until the chalk mark on the drill reaches the face of the hole. This method, however, does not ensure great accuracy.

The depth of a blind hole can be periodically checked during drilling with a depth gauge. But since, in this case, the drill has to be backed out of the hole and replaced after measurement, the operator's productivity is considerably reduced.

It is often necessary to drill only part of a hole, with half the circumference or less, as shown in Fig. 71*a*. In this case the work is clamped in a vise together with a processing pad (Fig. 71*b*), and the hole centre is marked and drilled in the usual manner.

When drilling *deep holes* (more than five drill diameters long), it is advisable to commence with a short drill, and then continue drilling with a standard drill to

the full length. The standard drill will be given the required direction and will not depart from the true hole axis as it proceeds into the workpiece.

When drilling a deep hole, the drill should be backed out of the hole from time to time, without stopping the machine, and the chips removed from the flutes. It is also necessary to see that the drill length corresponds to the hole depth, i.e., that the length of the hole does not exceed that of the drill flutes; otherwise the chips will be trapped in the flutes and the drill will break.

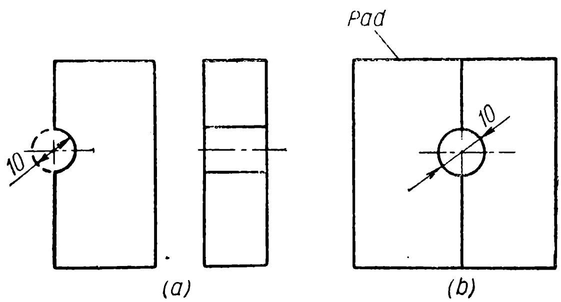


Fig. 71. Drilling a part of a hole

Laying out holes for drilling is an inefficient operation, and is therefore mainly used when the batches of work are too small to justify the expense of making a drilling jig.

The centres of small holes are laid out by centre punch marks at the intersection of the axes of symmetry of the hole (Fig. 72*a*). If, however, the diameter of the hole is large and the permissible deviation of the axis of the drilled hole from the laid-out axis is small, the circumference of the hole to be drilled is then scribed, with the point of intersection of the axes of symmetry as its centre. The circumference line is then prick-punched with a fine centre punch, as the line scribed by the dividers is shallow and can be easily obliterated during machining (Fig. 72*b*).

Before drilling laid-out holes, they are spotted by drilling to about one-half the depth of the drill point. The drill should then be withdrawn and the circular impression should be checked to see if it is concentric with the scribed circle; if they are not concentric, this means that the drill

is running to one side of the centre of the hole (Fig. 72c), and it will be necessary to cut two or three shallow grooves with a cape chisel from the centre in the direction in which the drill must be "drawn" (Fig. 72d) before starting the drill in the hole again. This may have to be repeated several times and is an extremely fussy and time-consuming job.

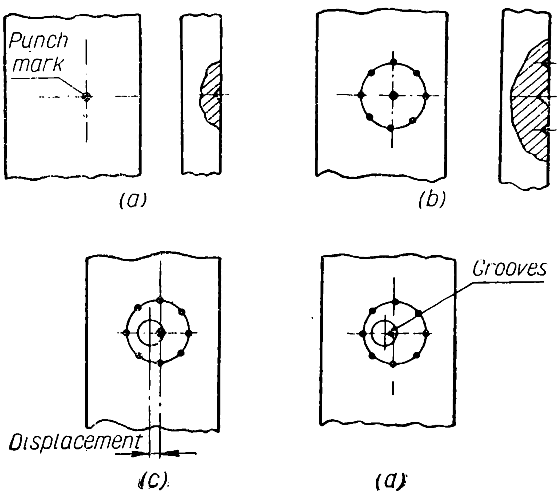


Fig. 72. Drilling laid-out holes

Work in which laid-out holes are to be drilled must be clamped to the drilling machine table with strap clamps, machine vises or other fixtures. In clamping the work, care must be taken to locate it so that the centre of the laid-out hole coincides with the drill axis and that the supporting surface of the workpiece is perpendicular to its axis, otherwise the hole will be drilled out of line.

Drilling with jigs, as we have already mentioned, is performed when a higher machining accuracy is required for a sufficiently large lot of parts. This method is much more efficient than laying out holes and then drilling; the laborious and expensive laying-out operation is no longer necessary, nor is it necessary to set up each workpiece before machining it; the work is clamped much quicker, operator fatigue is reduced, and so on. Moreover, the

quality of holes drilled in jigs is much higher. Constant locating elements and jig bushings which guide the drills increase machining accuracy and ensure part interchangeability.

The following main rules must be observed in drilling holes:

1. Clamp the work properly and firmly, without distortion, onto the table of the drilling machine and as close as possible to the surface of the table. Use side clamps instead of top clamps wherever possible, so as to reduce the necessary length of the drill and to create the best conditions for its operation.

2. Advance the drill to the surface of the work only after the drilling machine has been switched on, taking care that it only just contacts the surface of the work to avoid chipping of the drill lips.

3. Never stop the machine when the drill is in the hole: first back the drill out of the hole and only then stop the machine, as otherwise the drill may break.

4. Sometimes, during drilling, a distinctive metallic screech or squeak is heard. This indicates departure of the hole from the true axis or that the drill is dull. In this case, stop the feed immediately, back out the drill and stop the machine.

5. Secure drill chucks and taper-shank drills either directly in the spindle or through one sleeve only. The use of a large number of sleeves will only increase the runout of the lips of the drill.

6. Before mounting taper-shank drills in the spindle, place a pad of copper or lead under the drill point and secure the drill in the spindle by gradually lowering the spindle onto the shank of the drill (with the aid of the pilot-wheel or lever). Never force the drill into the spindle with a hammer or by knocking it against the work.

7. Always use the special drift for removing the drill from the spindle. When doing so, always place a piece of wood or other soft material on the drilling machine table so as not to damage the lips of the drill as it drops out of the spindle. Never use wrenches, files or other tools for this purpose, as they may damage the spindle or the tang of the drill.

8. Always drill with the speeds and feeds specified in the process sheets or selected from handbook tables.

9. Before commencing to work, always check the drilling machine by running it idle. If the spindle rotates normally, without any play, and the table and other mechanisms travel smoothly without binding, set up the machine to the required speeds and feeds.

10. In all cases, before starting to work, study the drawing of the work or the process sheet for the given operation.

3. Enlarging Holes

Enlarging a hole means increasing the diameter of a previously drilled hole with a drill of larger diameter. Enlarging is usually performed for drilling holes larger than 25 mm from the solid.

As we already know, the chisel point at the end of the web does not actually cut, but extrudes the material before it; therefore, with an increase in the diameter of the drill and, consequently, in the thickness of the web, the axial pressure increases and the cutting process is more difficult.

To eliminate this detrimental effect when drilling holes over 25 mm in diameter, a hole of about half the size is first drilled and then enlarged with a second drill to the required diameter. In this case, the chisel point of the second drill does not participate in the drilling action and the feed pressure is reduced. As a result, the departure of the drill from the true hole axis will be much less, thus allowing the feed to be increased by from 50 to 100 per cent as compared with drilling holes from the solid with a drill of the same diameter.

If we consider that the cutting speed for enlarging holes may be the same as for drilling from the solid, we can see that the time for machining a hole, including enlarging, will be considerably reduced.

It should be remembered that only previously drilled holes may be enlarged. It is not advisable to enlarge cast and punched holes and holes obtained by similar methods, as then the drill will be liable to considerable departure from the true hole axis because the centre of the previously made hole frequently does not coincide with the axis of the drill.

In recent years, a special trepanning drill has been designed, which enables holes with diameters of 50 mm

and over to be drilled in general-purpose drilling machines without resorting to enlarging. This method consists in cutting an annular groove in the solid metal, the resulting core being suitable for manufacturing other parts.

Fig. 73 shows the principle of the trepanning method. An annular groove is gradually cut in solid metal by blades located at different heights and removing chips of different widths.

The procedure and rules to be observed in enlarging holes are similar to those for drilling.

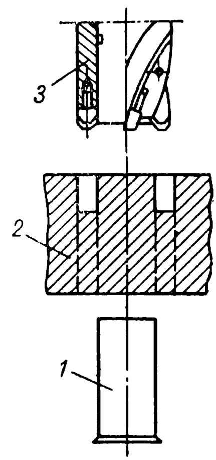


Fig. 73. Trepanning:
1—core, *2*—work being machined, *3*—trepanning drill

4. Spoilage During Drilling Operations and Methods for its Prevention

Any deviation from the shape, size and other requirements specified in drawings, resulting in the process of manufacturing any given part is called spoilage. Spoilage may be *final* (the work cannot be used; such spoilages are called rejects); or it may be *repairable* (the work can be used after extra machining).

Spoilage is generally caused by infringing the machining process, by carelessness and inattention on the part of the operator in performing one or more of the prescribed passes, incorrect setup of the drilling machine, wrong use of tools, etc.

The following main types of spoilage are met with during the drilling of holes on drilling machines:

Rough surface of drilled hole. This may be due to working with dull or improperly sharpened drills; excessive drill feed; insufficient cooling of the drill or use of wrong cutting fluid.

These types of spoilage can be prevented by checking the angles of the drill (after sharpening) with a special combination gauge before starting work; to drill only with the feeds and speeds indicated in the process sheet and by regulating the flow of the coolant to the drill.

The hole diameter is larger than specified. This may be due to one of the following causes: wrong size of the drill used; poorly sharpened drill—one lip longer than the other, unequal lip angles, the chisel point is not at the centre; play of the drilling machine spindle; worn jig bushings.

These causes may be avoided by systematically checking the angles of the drill after sharpening, the runout of the spindle, and the condition of the jig bushings, before commencing work.

Displacement of the hole axis may be due to incorrect layout (when drilling previously laid out holes); to shifting of the work during drilling, drill runout in the spindle, or departure of the drill from the true hole axis.

Displacement of the centre line of the hole can be avoided by laying out the holes accurately and by spotting the hole drilling to a small depth, checking the clamping of the workpiece before starting work; by sharpening the drill properly and also by eliminating drill runout.

The axis of the hole is not true; this may be due to improper mounting of the workpiece on the table or in the jig; to chips or other foreign matter under the workpiece; to the table not being perpendicular to the spindle; or to excessive pressure on the drill when feeding it. This type of spoilage can be avoided by carefully checking the setup of the workpiece and seeing that it is firmly clamped; by wiping the machine table perfectly clean of all traces of chips and dirt and truing the table before commencing work; and by not exerting too great a pressure on the drill when using the hand feed.

5. Causes of Excessive Drill Wear and Breakage

Premature wear and breakage of drills are caused, mainly, by incorrect operation and faulty manufacture. The following types of drill wear and breakage occur in practice.

Chipping of the lips due to drilling at excessive cutting speeds, insufficient and poor cooling of the drill, incorrect sharpening (excessive lip relief and chisel point angles), faulty heat treatment of the drill (overheating, decarburization, low initial hardness, etc.).

Dulling of lips results from prolonged drilling without sharpening, excessively heavy feeds, and slipping of the drill in its sleeve, chuck or spindle.

Rapid and unequal wear of the drill lips results from excessively high cutting speed; unsymmetrical lips, leading to unequal loads on them; and overheating of the drill due to insufficient cooling.

Destruction of margins due to their excessive width, which contributes to an increase in friction and the welding of chips on them.

Drill breakage is usually due to drilling with feeds exceeding those permissible for the size of the drill used (especially when drilling with small-diameter drills); high feed as the drill breaks out of the hole; worn margins, whereby the back taper of the drill from point of shank is reduced to make the drill practically cylindrical; departure of the drill from the true hole axis; the flutes of the drill being too short for the escape of the chips, as a result of which the latter jam up in the flutes; cracks in the carbide tips, or the carbide tips being incorrectly brazed in the drill; the structure of the workpiece is not uniform and the drill runs into blowholes or hard inclusions, etc.

Drill breakage and premature wear can only be avoided by a proper study of all their causes, and by strict observance of all drilling machine operation and maintenance rules.

6. Drill Selection

The drilling machine operator's productivity depends on many factors, one of which is the proper selection of a drill to suit the material being machined.

In spite of the fact that the type of drill and its diameter are indicated in the process sheet, the drilling machine operator very frequently, for instance, in the absence of the specified drill, has to decide for himself whether or not to use a definite type of drill, or to substitute another one for it.

The following main recommendations for selecting and using drills are intended to help drilling machine operators in solving these problems.

High-speed steel drills should be mainly used for drilling holes in unhardened steels; grade T15K6 carbide-tipped drills should be used for drilling holes in hardened steels.

Double-lipped drills, drills with thinned webs and split-point drills should be used for drilling holes in cast iron. These drills permit drilling cast irons with feeds over 30 per cent above the permissible feeds for drills of standard design. It should, however, be remembered that these drills can only be used with jig bushings, as otherwise the holes will be drilled out-of-round. Grade BK8 carbide-tipped drills are even better for these purposes. These drills reduce drilling time by $^1/_2$ or $^1/_3$ in drilling grey cast iron as compared with time required for drilling with high-speed steel drills of standard design. It is advisable to drill large holes (over 50 mm diameter) with trepanning drills.

Holes in sheet steel and cast irons should be drilled with drills having an increased point angle; drills with spur points should be used for drilling holes in sheets of nonferrous metals, plastics and wood.

7. Core Drilling

In order to improve the shape of drilled, cast or punched holes (i.e., to eliminate out-of-roundness, ovality and other defects), and to improve their surface finish, holes are subsequently machined with core drills. These are three- or four-flute drills, with three or four cutting edges correspondingly; they have no web or chisel point and consequently they are guided into the hole in a better manner than ordinary twist drills, thus providing more accurate performance; holes of 3rd and 4th grade accuracy can be obtained with core drills.

Usually, core drilling is an operation intermediate between drilling and reaming; for this purpose, a small allowance is left for finishing the hole with the reamer (just as an allowance is left for core drilling). If the hole is not to be reamed after core drilling, the diameter of the core drill should be the same as the required final diameter of the hole.

Core drilling is a more productive operation than ordinary drilling since with the same cutting speeds, the feeds used may be 2.5 to 3 times larger.

As enlarging holes with core drills is much more efficient than redrilling with a larger drill, and ensures a greater hole accuracy, it is recommended to enlarge holes

with core drills wherever possible, instead of drilling with a larger drill.

The procedure for using core drills is similar to that for using ordinary twist drills.

8. Reaming

Reaming is the final operation in the process of making holes of accurate dimensions and shape. It is performed with a reamer after using a core drill in the holes. A reamer is a cutting tool with a large number of teeth, the chamfer and starting taper of which form cutting edges which remove a very thin layer of metal.

Single-pass rough reaming removes rough traces of previous machining (drilling, core drilling). A layer of metal from 0.15 to 0.3 mm is removed, and a hole of 3rd grade accuracy is obtained with a surface finish up to the 6th class.

In double-pass (finish) reaming the thickness of the removed layer is even less—from 0.04 to 0.2 mm. With a good reamer it is possible to obtain a hole of 2nd grade accuracy with a surface finish up to the 7th class.

Allowances for fine (precision) reaming, performed after finish reaming, are half those specified for finish reaming, holes thus reamed are of the 1st and 2nd grade accuracy with a surface finish up to the 8th class. Adjustable reamers are usually employed for precision reaming; they are operated at low cutting speeds (1.5-2 m/min) and light feeds (0.2-0.5 mm/rev).

It should be noted that the accuracy grades mentioned above apply only to holes reamed in steel; holes in cast iron can be reamed to one class higher.

A properly reamed hole is one whose axis coincides exactly with that of the reamer. To ensure this, reamers are not fastened rigidly in the machine spindle but in special floating holders and reaming is performed without jig bushings.

When working with reamers remember that the diameter of the reamed hole will always be slightly larger than that of the reamer (by approximately up to 0.02 mm), as the hole is somewhat enlarged by the action of the reamer. However, when using a worn reamer or when reaming holes in ductile metals, the hole may be reamed

to a smaller diameter than that of the reamer. Therefore, all these factors should be considered in selecting a reamer.

When reaming, always use a cutting fluid as otherwise the hole will be reamed oversize and the resulting surface will be uneven, gouged or scored. This may damage and even break the teeth of the reamer due to its seizing in the hole.

A poor surface finish of the reamed hole with lines, scoring and traces of chattering may be due to rough preliminary machining of the hole, excessive reaming allowance, incorrect sharpening or dulling of the reamer, or to incorrect feed or cutting fluid.

9. Counterboring, Countersinking and Spotfacing

These operations are performed with various types of tools. Counterboring and countersinking are used for enlarging previously drilled holes for a part of their length to make recesses for the heads of screws, bolts and other

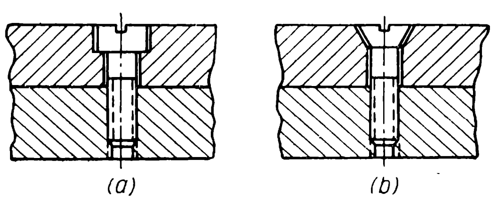


Fig. 74. Counterboring and countersinking:
(*a*) filister-head screw, (*b*) flat-head screw

parts. Counterbores make a cylindrical recess at the entrance of the hole for filister-head screws, when these heads must not extend above the surface of the screwed parts, as shown in Fig. 74*a*. If the screw head is tapered (Fig. 74*b*), a countersink must be used.

Spotfacing tools machine (finish) the faces of bosses for washers, thrust rings, nuts and other parts. This operation is called spotfacing.

Cutting speeds and feeds for counterboring, countersinking and spotfacing are similar to those for core drilling.

10. Tapping

There are two typical cases of tapping in drilling machines; in one, the tap has to be screwed out of the hole, while in the other this is not necessary. The first case is typical for tapping blind holes, and the second is typical for threading through holes in comparatively short components, such as in nuts.

Not all drilling machines can be used for tapping blind holes. After tapping a blind hole, there is only one way to withdraw the tap—by screwing it out; for this, the machine spindle, with the tap fastened in it must be able to be reversed. For this reason modern drilling machines are equipped with special reversing devices which rotate the spindle in a direction reverse to the tapping direction (left-hand) at a speed higher than the tapping speed. The direction of spindle rotation on machines without reversing devices can be reversed by switching over the phases of the electric motor either automatically (with an electric reverse) or by hand.

The thread of blind holes is cut with machine taps with a short chamfer, permitting threading as close as possible to the bottom of the hole. Special safety chucks are used to prevent the tap from breaking when it reaches the bottom of the hole. These chucks automatically stop the rotation of the tap (though the spindle continues to rotate).

Tapping through holes in drilling machines is mostly performed in nuts and similar items. In these cases, tapping can be performed on ordinary nonreversible drilling machines with long straight tapper taps or with bent-shank tapper taps.

When working with a long straight tapper tap, the nuts, tapped consecutively, accumulate on the shank of the tap until it is full of tapped nuts, then the machine is stopped, the tap removed from its chuck and the nuts taken off. After this the tap is replaced in the chuck and work is continued as before.

A better and more efficient method of tapping nuts is with a bent-shank tapper tap (Fig. 75), which makes the process continuous as there is no need to stop the machine and remove the nuts. Each tapped nut is pushed along the shank by the following nut, comes off the working part of the tap, and falls down a chute into a box.

In the process of tapping holes the material of the work flows to some extent into the grooves of the thread of the tap (under the action of the feeding force and the tap rotation), thus reducing the diameter of the hole. The

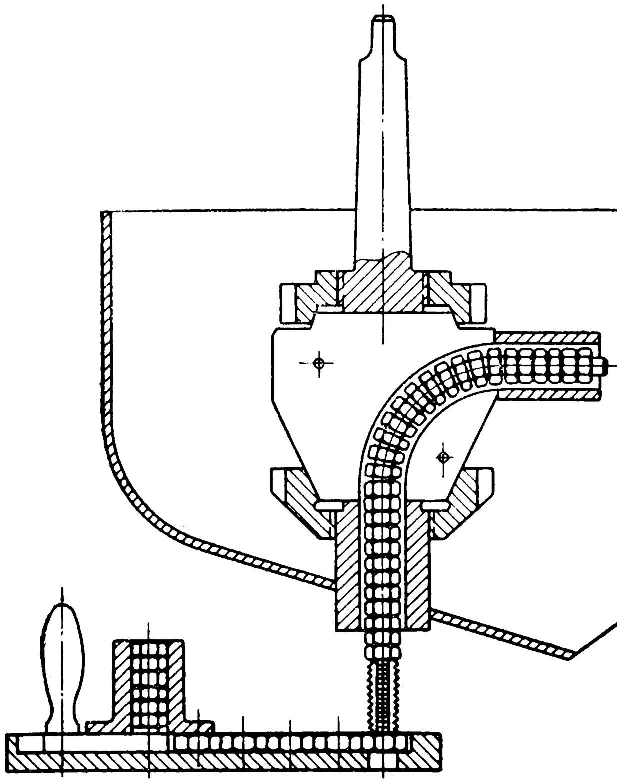


Fig. 75. Tapping nuts with a bent-shank tapper tap

diameter of the hole should be somewhat larger than the minor diameter of the thread. For this reason, drills must be selected according to the process sheets or special tables (see Appendix 8).

It is not advisable to tap holes obtained by casting, punching or similar methods. These holes should always be enlarged or core drilled before tapping to remove any

adhering sand, scale or work hardening (top layer of metal with increased hardness), as otherwise the taps will wear rapidly and the quality of the thread will be poor.

11. Setting up a Drilling Machine

Before commencing work on a drilling machine it must be set up.

Setting-up is the preparatory work of installing and adjusting the cutting tool and jig or fixture for clamping the workpieces, inspecting the machine and checking its operation by a trial run, and setting the machine for the required spindle speed and tool feed specified in the process sheet or selected from special tables.

In mass and lot production the setting-up of machine tools (including drilling machines) is usually carried out by a highly skilled setter-up, while in piece and small-lot production the operators themselves set up their machines.

Irrespective of who sets up the machine, the operator must inspect it and check its operation in an idle run. In doing so, he must see that the spindle rotates without excessive play and that its vertical travel, like that of the table, is smooth.

All defects discovered in the drilling machine should be immediately reported to the foreman or setter-up.

12. Reducing Machining and Handling Time

Labour productivity in drilling operations can be increased by reducing the machining and handling time, and also by efficient ogranization of work on the drilling machines.

Machining time can be reduced by increasing the feed and the cutting speed, by using multiple-spindle drilling heads and combination tools, by reducing allowances, by combining two or more operations, etc.

Handling time can be reduced by using quick-acting clamping fixtures and quick-change tools, by mounting and removing the workpieces without stopping the machine (multistation fixtures), and by the mechanization and automation of manual operations.

Each of these factors influences labour productivity to a certain degree, but as the experience of leading workers

and scientific research show, any marked increase in productivity can be achieved only by the simultaneous reduction of both machining and handling times.

For instance, consider an operator, using a lay-on jig plate and a high-speed steel drill, who drills holes in 100 workpieces in 7 hours of work. Since the lay-on jig plate is far from being a perfect fixture (its mounting, adjustment and clamping of the work take a great deal of unproductive time), machining time in this case constitutes only 50 per cent of the total 7 hours (3.5 hours), while the remaining 50 per cent is handling time.

In order to raise productivity, let us assume that we decide to double the cutting speed by using a carbide-tipped drill instead of a high-speed steel drill. Now the machining of 100 parts will require only 1.75 hours instead of 3.5 hours. We shall, indeed, raise productivity, but (as will be seen later) to only a very insignificant amount, because the handling time has remained unchanged (the same lay-on jig plate is used). This is illustrated by the following simple calculation:

1. In drilling 100 holes with a high-speed steel drill in a lay-on jig, the time expenditure is 3.5 hours machining plus 3.5 hours handling time, a total of 7 hours.
2. In drilling 100 holes with a carbide-tipped drill in the same jig, machining time constitutes 1.75 hours and handling time 3.5 hours; a total of 5.25 hours.

As a result, the machining time for 100 holes is reduced by 1.75 hours, which corresponds to an increase in productivity of only 33 per cent.

Let us now, in addition to replacing the drill, replace the jig, say by a multistation fixture. Let us assume that the handling time in this case is also reduced by 50 per cent. Now, in drilling 100 holes we shall require 1.75 hours machining time and 1.75 hours handling time, i.e., a total of 3.5 hours, which corresponds to an increase of productivity by 100 per cent.

As we see, in this case, by simultaneously reducing machining and handling times we have achieved a considerable effect—productivity has been doubled.

We have already shown that machining time can be reduced by increasing both cutting speed and feed. Experience of progressive drilling machine operators shows that increasing the feed is more effective than increasing

the cutting speed. Thus, for example, research has shown that an increase of 15 per cent in the cutting speed is accompanied by a reduction of the drill life by 50 per cent, while a similar increase of feed reduces the life of the drill by only 30 per cent.

Therefore, it is more advantageous to increase the feed and, in order not to reduce drill life, to slightly reduce the cutting speed. But, since the feed of the drill is limited by its strength, the load on the drill, i.e., the detrimental effect (resistance) of the chisel point on the operation of the drill must be reduced. This is achieved by thinning its web. But it does not follow from this that high cutting speeds—high-velocity drilling—is not efficient. In some cases, high-velocity drilling is already being successfully employed for drilling holes in metals producing brittle chips (cast iron, bronze), and for drilling shallow holes (up to three drill diameters) in steel.

In the future, with the use of solid cemented-carbide drills with helical flutes for chip disposal instead of carbide-tipped drills, and improvement in drilling machine design, high-velocity drilling will permit a further increase in the productivity of drilling holes in any metal.

As already stated, handling time can be reduced by improvements in tooling and by the mechanization and automation of the drilling process.

An example of mechanization is the use of jigs which automatically clamp the work and relieve the operator of a number of manual operations.

A sketch of such a jig for drilling holes in a round workpiece is given in Fig. 76.

Strap *2* is connected with the spindle sleeve through yoke *3*. When the spindle is lowered to advance the drill to the workpiece, the strap gradually opens the valve *1* of an air distributor, which delivers compressed air from the air line to air cylinder *5*. The cylinder piston, in its travel, actuates clamp *4* which clamps the workpiece firmly in the jig before the drill touches it. During reverse spindle travel, after the drill leaves the hole, valve *1* delivers air to the other end of the cylinder. The piston rod travels in the reverse direction and clamp *4* releases the workpiece.

Such a device, by eliminating two manual operations (clamping and unclamping the workpiece), reduces operator's fatigue and considerably increases productivity.

However, in spite of such a mechanized jig, handling time and operator's fatigue continue to remain considerable. The operator has to mount and remove workpieces with one hand while continuously operating the drill spindle with the other. The drilling machine runs idly during the loading and unloading of the work.

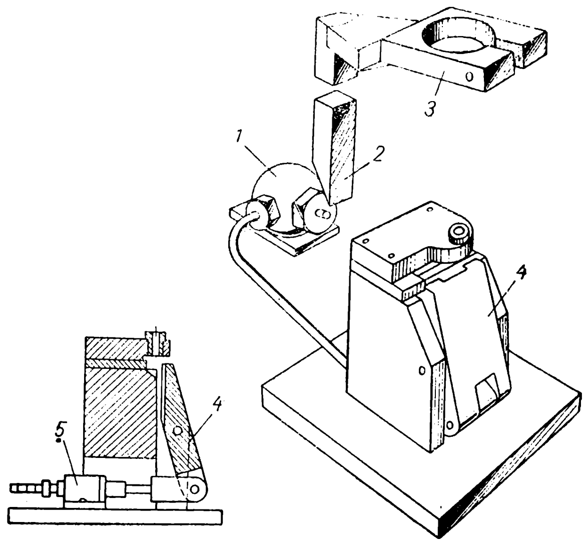


Fig. 76. Automatic clamping jig

A still greater increase in productivity can be obtained by covering the handling time with the machining time—for instance, by loading and unloading the work during the working travel of the spindle. This can be achieved with the aid of the device (a suspended-type jig plate) shown in Fig. 77. Here, a cylindrical workpiece is to have a hole drilled in one side; it is placed in an inclined chute *1* (Fig. 77*b*) bolted to support *8*. The workpieces roll freely one after another down the inclined chute until they reach spring-loaded stop *6* (Fig. 77*a*). When the spindle *3* is lowered, jig plate *4* locates and clamps the next workpiece for drilling with the aid of V-block *2*. It simultaneously depresses stop *6* with the aid of two pins *5*, thus allowing the drilled work to roll down into a tote box *7*.

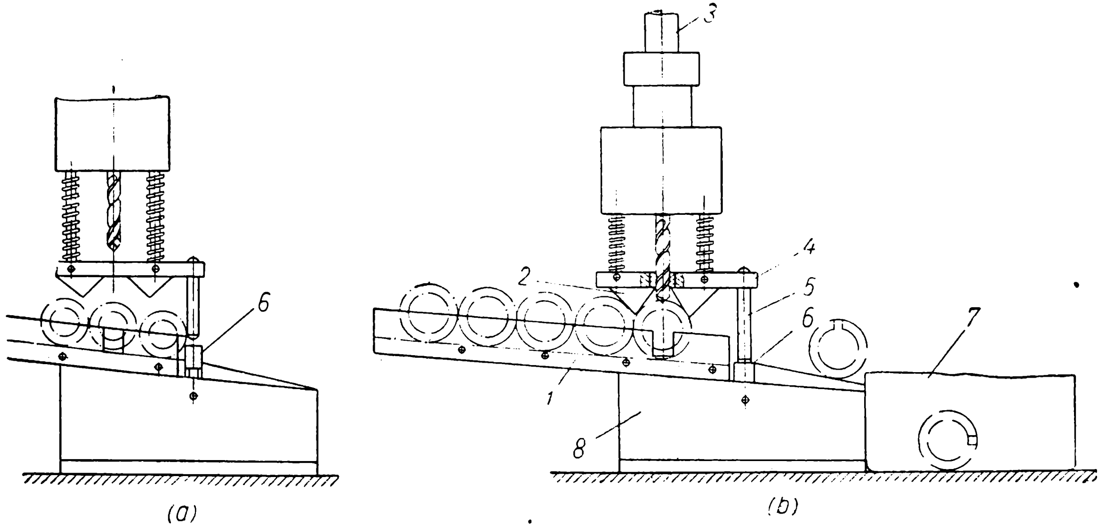


Fig. 77. Automatic loading and clamping fixture for drilling machines

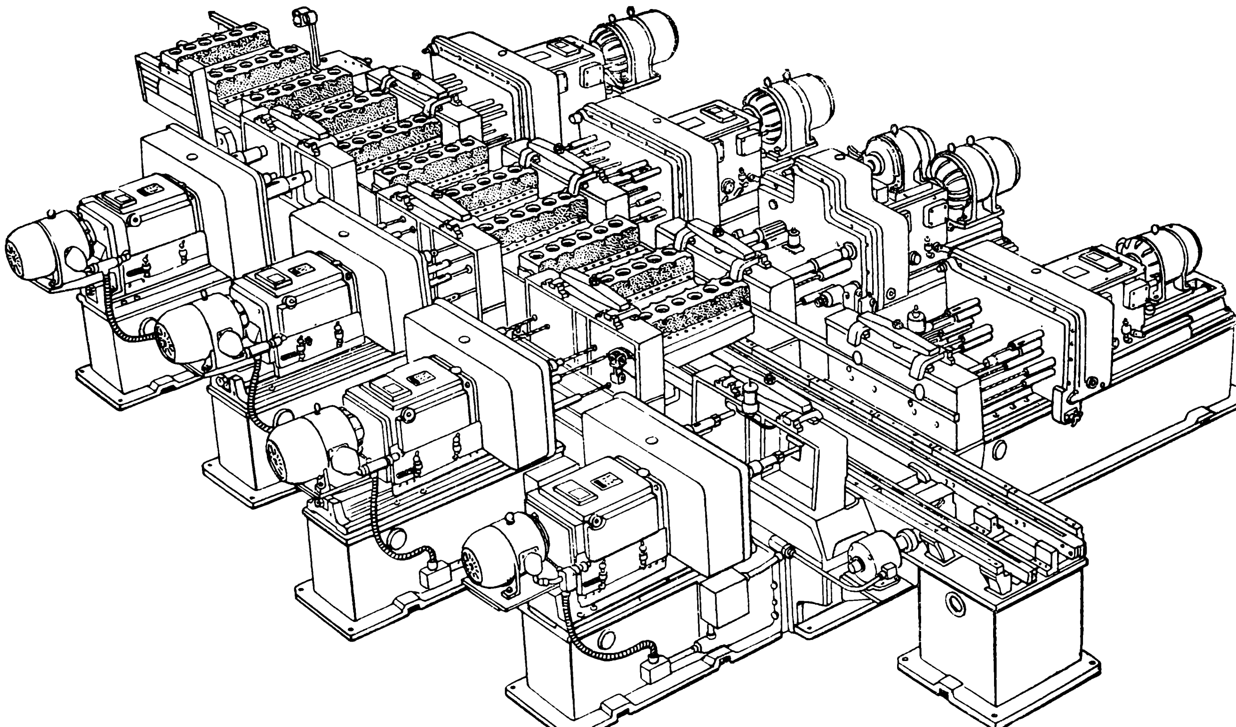


Fig. 78. Automatic transfer machine built up of horizontal-spindle drilling units

In this manner, the work is clamped and removed during the working stroke of the spindle thereby increasing the operator's productivity.

If we add to this device a magazine or hopper, which can be loaded with a large quantity of parts, and feed the spindle with a cam, link or other mechanism, the entire process will be automatic. In this case the operator's role will be limited to the periodic loading of the hopper and he will be able to operate several machines simultaneously.

In recent years the machining of holes has been performed on automatic transfer machines of various design.

Fig. 78 shows an automatic transfer machine built up of standard drilling units with horizontal spindles, as used in automobile plants. The entire process of machining and transferring the parts from one operation to another in the machine is automatic. The operator only has to watch the operation of the machines and eliminate defects as and when they appear.

Chapter X

FUNDAMENTALS OF PRODUCTION ECONOMICS

1. Rate Setting

Proper accounting of the amount of labour expended (labour input) by each worker in a unit of time for performing a particular task is highly important.

The criterion of the increase in labour productivity is the time standard. Each increase in the productivity of labour entailed in the performance of a definite task is accompanied by a corresponding lowering of the time standard. *Rate setting* covers the study of work processes the determination of the working time input, the establishment, implementation and control of theoretical technical rates and standards.

The standards are established on the basis of scientific calculations and the analysis of an entire series of practical operations performed under correct conditions.

The time input for a definite operation is determined by stop-watch timestudy (the timed standard) or is calculated from definite formulas (the theoretical time standard).

The *theoretical time standard* is calculated from the sum of the machining time, handling time, setup time, servicing time and time for rest and personal needs.

The machining time (t_m) is the time required directly for machining the given piece of work. It is calculated on the basis of the productivity of the equipment and the cutting speeds and feeds.

For drilling machine operations, the machining time is calculated from the formula given on page 94.

Handling time (t_h) is the time required for loading, clamping, releasing and removing the work, starting up and stopping the machine, measuring the dimensions of the work, advancing and withdrawing the tool, etc.

Servicing time (t_s) is the time required for servicing the workplace before starting work, laying out the tools, servicing the machine, etc.

The time for rest and personal needs of the operator (t_f) includes all interruptions on the part of the operator for rest and personal needs. It is also called the fatigue allowance.

Setup time (t_{su}) is the time required for receiving a job, instructions, reading drawings, operation charts, setting up the machine, handling over finished work, etc.

Thus, the time standard can be expressed by the following formula:

$$t = t_m + t_h + t_s + t_{su} + t_f.$$

2. Wages

In socialist industry, wages are that part of the national income which is paid directly as money to the workers and employees.

There are two basic wage systems for workers: the *piece-rate* and the *time-rate* systems. In the piece-rate system, the worker's earnings depend on the quantity of work he produces. In the time-rate system, his earnings depend on the amount of time he works.

The piece-rate system combines to the fullest extent the personal interests of the worker with the interests of society and for this reason is most widely used in socialist countries.

Piece rates are based on what is called the tarif scale, which determines the basic wages for a worker of the 1st category (the lowest degree of skill), the tarif coefficients and also rate-setting conditions.

Piece-rate payment cannot be organized unless the skills required for performing definite jobs are properly determined. For this purpose use is made of tarif handbooks, indicating the knowledge required for workers of definite qualifications and the jobs which a worker of a definite category of skill must be able to perform independently, and examples of jobs typical for definite categories of skill. With the aid of these handbooks, the different kinds of jobs for each category of skill can be easily and precisely found.

The wages per hour or per day are determined from the basic tarif scales. These basic tarif scales are established for workers of the first, or lowest, category of skill. The tarif rates for workers of other categories of skill are found by multiplying the tarif rates for workers of the 1st category by the corresponding tarif coefficient. The ratio of payment for workers performing jobs of various complexity is determined according to the tarif scale. All engineering enterprises in the Soviet Union work on a tarif scale consisting of six categories and corresponding tarif coefficients.

3. Planning Production

In order to ensure continuous, uninterrupted operation, all Soviet industrial enterprises draw up current and long-term production plans based on the state plan. Current plans cover immediate periods of time (year, quarter) while long-term plans are drawn up for longer periods (5, 7 and 15 years).

Current planning consists in drawing up a combined technical, production and financial plan, which is usually drafted for the coming year and divided into quarterly plans. It is based on the targets of the long-term plan but with more precise indices for the planned period, and coordinates the development of production technique, economics and finances of the enterprise.

The combined technical, production and financial plan of any given enterprise consists of the following sections:

(a) the production plan;
(b) the plan for technical development;
(c) the plan of organizational and engineering measures;
(d) plan of material and technical procurements;
(e) plan of labour power;
(f) production costs plan;
(g) financial plan.

All the other sections of the combined technical, production and financial plan are based on the production plan, which includes both commodity and gross production.

Commodity production of an enterprise includes all its finished products about to be sold.

Gross production includes the entire volume of work performed at the enterprise for ensuring the output of commodity production, including products in the process of production.

The criteria of the fulfilment of the production plan of any enterprise are: its gross and commodity output; the fulfilment of the plan of production of each item listed in the plan, the reduction of production costs, the implementation of new techniques, etc.

In addition, every Soviet enterprise draws up monthly, ten-day, daily and shift operative plans for each shop, production section and workplace.

4. Profitable Production and Production Costs

Most Soviet industrial enterprises operate on a *self-supporting basis*, i.e., all their expenses are covered by their returns, thereby making the collective of the enterprise materially interested in the results of the work of their enterprise.

An enterprise will operate at a profit only if it systematically fulfils its production-financial plan and reduces its production costs.

The *cost of production* in any industrial enterprise is equal to the sum of all expenses incurred in acquiring the means of production plus all wages together with insurance and other charges and payments for services incurred in the manufacture and sale of production. Production costs include the cost of materials, labour power, transport and overhead expenses. The cost of materials, labour and transport are called *direct expenses*. Indirect expenses are made up of shop or departmental and factory overhead expenses. *Shop or departmental overhead expenses* are all the expenses of a given shop or department entailed in supporting the basic production, and in shop management. *Factory overhead expenses* consist of all administration and general management expenses.

Overhead expenses affect the production cost of any manufactured article; they are expressed in percentages of the actual wages paid to the production workers.

The higher the productivity of labour and the lower the overhead expenses, the lower will be the cost of pro-

duction of the manufactured articles and the higher the profit of the enterprise.

Cost accounts are drawn up for each article manufactured at an enterprise; these accounts are the basis for determining the production costs. We distinguish: *planned* and *report* accounts.

Planned accounts determine the production cost of each product of the enterprise manufactured on the basis of progressive rates and standards of utilizing equipment, labour, consumption of material, fuel and power.

Report accounts are computed from the actual reports of materials consumed, labour consumption, transportation and actual overhead expenses.

In a well-managed enterprise the report cost should be less than the planned cost.

Chapter XI

WORKPLACE ARRANGEMENT. LABOUR SAFETY

1. The Drilling Machine Operator's Workplace

The drilling machine operator's *workplace* is a definite part of shop production space assigned for his machine, tools, fixtures, blanks, etc. The proper arrangement of his workplace and organization of work have a great effect on his efficiency, the quality of his work and the degree of his fatigue.

If his workplace is correctly arranged and his work well organized, no worker needs to waste time in looking for tools, fixtures and blanks, or in running around for job slips, drawings, etc.

Rational arrangement of the drilling machine operator's workplace will ensure the complete safety of his work, cleanliness, tidiness and normal working conditions.

Only those tools, jigs, fixtures and blanks which are required for the job in hand should be kept at the workplace. All others should be stored on racks or in a tool cabinet with shelves and compartments.

Each tool should have a place of its own in the tool cabinet. Small cutting tools should be kept in the top compartments, and larger tools and those less frequently used—in the lower compartments.

Measuring tools must be kept on a special shelf apart from cutting tools.

Wiping rags, brushes and scrapers must be stored in a separate box.

The layout of the drilling operator's workplace should give due consideration to the specific conditions of his work. All necessary equipment should be placed near the workplace so as to ensure the best possible organization of his work, reduction of handling and servicing time and the best conditions for safe work.

Fig. 79 shows a drilling machine operator's workplace. It comprises: upright drilling machine *1*, tool cabinet *2*, tote box for blanks and finished work *3*, and footboard *4* for the operator.

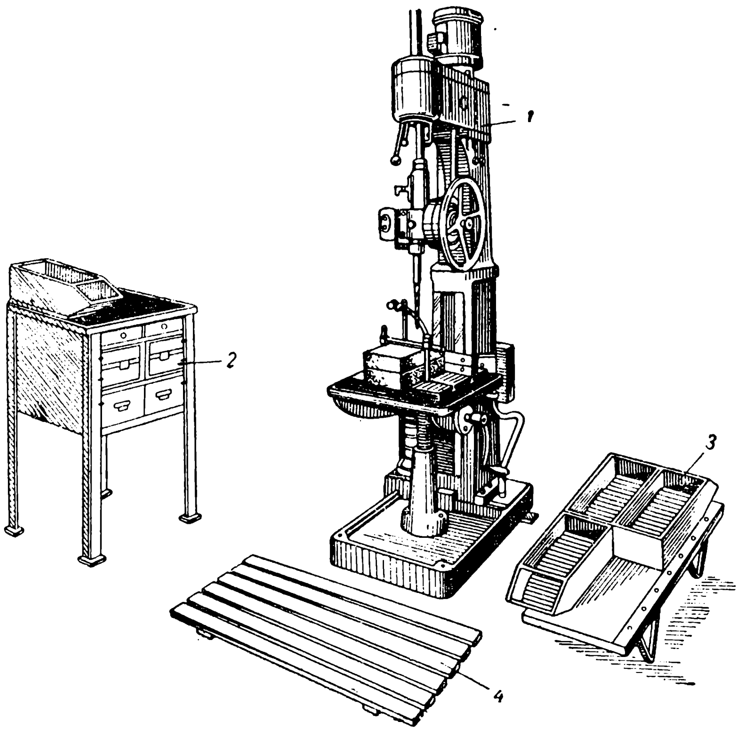


Fig. 79. Drilling operator's workplace

The workplace should be arranged so that all necessary equipment is concentrated as near as possible, without hindering the operator's freedom of movement. Everything that is used most frequently during operation should be located nearer at hand, while those items which are seldom employed should be farther away.

Drawings, operation charts and job slips should be placed where they can be readily consulted.

Small blanks machined in large quantities should be stored in a tote box near the drilling machine at the level of the operator's hands.

Finished work should be stored in a separate tote box near the drilling machine.

All items should be located in such a manner that there will be no need for the operator to bend down or to assume an inconvenient position each time he has to take up or put down an item. The tool cabinet should always be kept in strict order.

Healthy working conditions should be assured by such measures as efficient lighting, normal temperature, humidity and purity of the air, etc.

2. Importance of Accident Prevention

In a socialist country work is highly valued and great attention is given to protecting the worker's health. All the achievements of science and engineering in the U.S.S.R. are placed at the service of the workers in order to improve their working and living conditions. The Soviet state spends great sums annually on accident prevention.

As a result, the number of industrial accidents, including those in metal-working enterprises, steadily falls from year to year in the Soviet Union.

Most modern metal-working machine tools are equipped with all necessary guards and safety devices.

The aims of safety engineering are to prevent industrial accidents, improve labour conditions, and to instruct workers how to work safely, i.e., how to avoid accidents.

Therefore, each worker must be thoroughly familiar with the accident prevention rules in order to safeguard himself against accidents.

3. Causes and Prevention of Industrial Accidents

Accidents in machine shops may be due to many factors, the most important of which are:

(1) machine being out of order;
(2) absence of guards on various mechanisms;
(3) electrical wiring being out of order;

(4) operator's poor knowledge of safety rules;

(5) carelessness on the part of the operator, and others.

Accidents on drilling machines may also result from the work or tool being improperly clamped, disregard of the elementary rules for removing chips, working clothes and head-gear being worn incorrectly, heavy parts and tools falling on the operator's toes, etc.

Accidents very often occur during the drilling of holes, especially at high speeds, by fine chips flying out and injuring the eyes or burning exposed parts of the body.

Eyes should be protected by placing guard plates in the path of chips and by wearing goggles.

Never blow chips out of blind holes with your mouth or remove them from the machine by hand. They should be removed carefully with special scrapers and brushes, magnets or other devices.

Unguarded rotating machine parts, auxiliary and cutting tools are a serious danger to operators, as loose clothing, hands and hair may get caught in them. To avoid accidents, special guards must be used, the hair must be tucked in and covered and the sleeves tied neatly at the wrist.

Proper lighting, tidiness and cleanliness are very important for safety. Lighting should be uniform, and ample, without being glaring. The workplace must always be maintained clean and tidy.

Illness may be caused by polluted air in the shop. Artificial and skylight and window ventilation is used for purifying the air in factories and shops.

Illness may also be caused by using polluted cutting fluids which should therefore be filtered thoroughly and changed when necessary.

Each operator must strictly observe the following basic accident prevention rules:

1. Do not begin work on the machine until you are familiar with the safety instructions.

2. Never mount workpieces over 20 kg in weight on the machine without the aid of hoisting facilities or of a helper.

3. See that the workpiece and cutting tools are securely fastened.

4. Before switching on the electric motor place all machine control levers in the neutral position.

5. Do not leave the machine without supervision when it is running.

6. Always stop the machine before mounting and removing workpieces, changing tools, cleaning and oiling the machine, removing chips, and at the end of the shift.

7. Always wear goggles when machining holes in metal parts producing fine chips.

8. Never wear loose clothes when operating machines; sleeves must be tied at the wrist and the hair covered.

9. Never remove chips from a machine with your hands; always use special devices, magnets, etc.

10. Always keep your workplace clean and tidy.

11. Report all defects in machines, jigs, fixtures and tools to the foreman.

The factory rules and regulations must be strictly observed by all workers and employees.

4. Personal Hygiene

Personal hygiene is most essential to high labour productivity. It helps to eliminate conditions detrimental to the worker's health.

Physical exercise is an important measure for reducing fatigue. Therefore, all workers at the enterprise should participate in the "setting up" physical exercises which are organized at regular breaks, or intervals, during the shift and which give them new energy and improve their efficiency.

Personal hygiene is synonymous with cleanliness and tidiness.

5. Fire Prevention

Fires at an enterprise can be prevented by the strict observance of fire-prevention rules and regulations. A dirty workplace increases fire hazards, and workplaces should therefore always be kept clean and tidy.

At the end of each shift, all oily rags and waste used for cleaning the machine should be collected and placed in an iron box which can be closed with a lid.

The electric motor, all electrical appliances and lighting should be always switched off at the end of each shift.

Smoke only in specially allotted places.

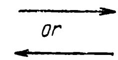
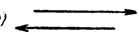
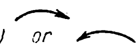
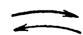
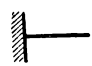
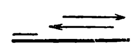
Should the electric motor of your machine become greatly overheated or burn out, call the electrician immediately.

In case of fire, telephone the fire brigade immediately and, until it arrives, do your best to extinguish the fire, using all available fire extinguishers, sand, canvas sheets, and water buckets.

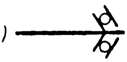
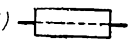
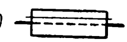
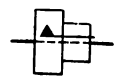
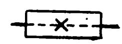
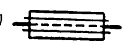
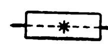
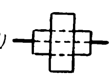
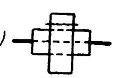
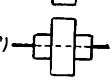
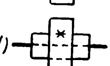
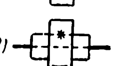
APPENDICES

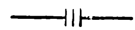
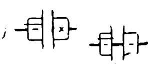
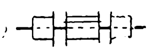
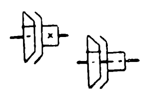
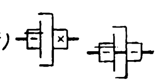
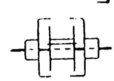
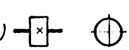
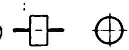
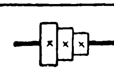
Appendix 1

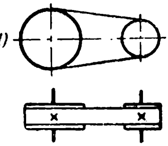
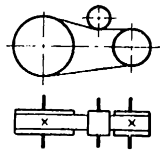
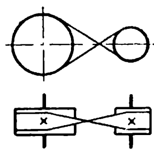
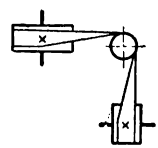
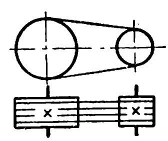
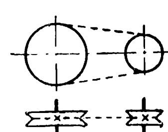
Graphical Symbols Used in Gearing Diagrams*

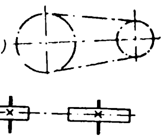
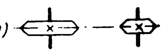
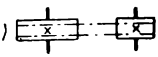
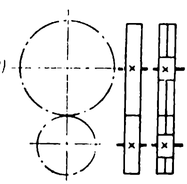
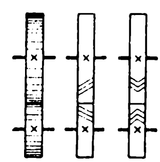
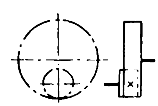
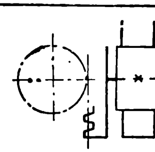
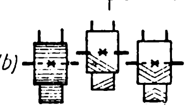
No.	Diagram (scheme) elements	Symbol
1	Nature and direction of motion:	
	(a) straight forward (in one direction)	(a) 
	(b) reciprocating	(b) 
	(c) rotary, in one direction	(c) 
	(d) oscillating	(d) 
	(e) shifting	(e) 
2	Shaft, spindle, axle, bar, connecting rod, etc.	
3	Rigidly fixed axle, rod, pin, etc.	
4	Stationary bearing for rod with reciprocating motion	
5	Shafts running in sleeve and anti-friction bearings:	
	(a) general symbol, without specification of type	(a) 
	(b) sleeve bearing	(b) 
	(c) sleeve bearing with ring lubrication	(c) 
	(d) plain thrust bearing	(d) 
	(e) radial ball bearing	(e) 

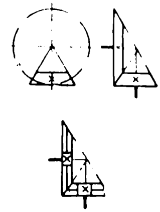
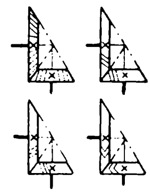
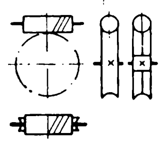
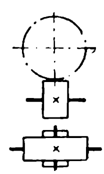
* Given in part.

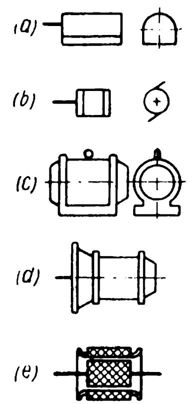
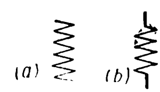
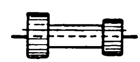
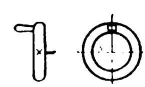
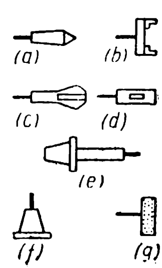
No.	Diagram (scheme) elements	Symbol
	(f) angular contact ball bearing	(f) 
	(g) double-ball thrust bearing	(g) 
6	Parts mounted on shafts:	
	(a) freely mounted	(a) 
	(b) sliding on feather	(b) 
	(c) engaged by sliding key	(c) 
	(d) fixed on key	(d) 
	(e) on splines	(e) 
	(f) on serrations	(f) 
7	Joints between two parts:	
	(a) freely movable	(a) 
	(b) sliding on feather	(b) 
	(c) fixed (general symbol)	(c) 
	(d) fixed by key	(d) 
	(e) serrated	(e) 

No.	Diagram (scheme) elements	Symbol
8	Jaw clutches:	
	(a) single-action	(a) 
	(b) double-action	(b) 
9	Friction clutches:	
	(a) general symbol, without specification of type	(a) 
	(b) single-action type (general symbol)	(b) 
	(c) twin type (general symbol)	(c) 
	(d) cone type	(d) 
	(e) twin cone type	(e) 
	(f) disk type	(f) 
	(g) twin disk type	(g) 
10	Pulleys on shaft:	
	(a) keyed	(a) 
	(b) idler	(b) 
11	Stepped pulley, keyed to shaft	

No.	Diagram (scheme) elements	Symbol
12	Flat belt drives: (a) open belt	(a) 
	(b) open belt with idler puller	(b) 
	(c) crossed belt	(c) 
	(d) angular belt drive	(d) 
13	V-belt drive	
14	Round belt and rope drive	

No.	Diagram (scheme elements	Symbol
15	Chain drives:	
	(a) general symbol, without specification of type	(a) 
	(b) roller-chain drive	(b) 
	(c) silent-chain drive	(c) 
16	Toothed gearing between parallel shafts with spur, parallel helical and herringbone gears:	
	(a) external gearing, general symbol, without specification of type	(a) 
	(b) ditto, but with spur, parallel helical and herringbone gears	(b) 
	(c) internal gearing	(c) 
17	Rack and pinion gearing:	
	(a) rack and pinion, general symbol, without specification of type	(a) 
	(b) with spur, helical and herringbone pinions	(b) 

No.	Diagram (scheme) elements	Symbol
18	Toothed gearing between intersecting shafts, bevel gearing: (a) general symbol, without specification of type (b) with straight, hypoid, curved tooth and herringbone gears	(a)  (b) 
19	Toothed gearing between crossed shafts: (a) worm gearing (b) crossed helical gearing	(a)  (b) 
20	Motion transmitting screw	
21	Nut on motion transmitting screw: (a) solid (b) split	(a)  (b) 

No.	Diagram (scheme) elements	Symbol
22	Motors: (a) general symbol, without specification of type (except electric motors) (b) general symbol for electric motors (c) electric motor mounted on feet (d) flange-mounted electric motor (e) built-in electric motor	
23	Springs: (a) compression (b) extension	
24	Double cluster-gear	
25	Handwheel	
26	Metal-working machine tool spindle noses for: (a) centre operations (b) chucking operations (c) bar stock machining operations (d) drilling operations (e) horizontal milling operations (f) vertical milling operations (g) grinding operations	

Machining operation chart

Name or index of article	Article drawing No.
Name of part	Part drawing No.

Name of operation	Operation No.	Shop
Material, grade, and U. S. S. R. State Standard (GOST)	Receive from	Deliver to

Blank cross section and size	Name and index of equipment		Power
Number of parts from one blank	Operation element No.	Name of fixture or jig	Index
Rough weight of______parts, kg			
Finished weight of______parts, kg	Cutting fluid		

Quantity of simultaneously		Job category	Setup time, mins	Time rate for______parts, mins				Rate for_____parts, roubles		Rated output per hour
machined parts	machines served			machining	handling	additional	per piece	setup time	per piece	

Setups and operation elements		Tooling			Calculated data				Machining conditions				Time, mins	
No.	Name and description	Cutting tools	Auxiliary tools	Measuring tools	Diameter or travel length, mm	Calculated machining length, mm	Number of cuts (passes)	Cutting speed, m/min	Revolutions or full strokes per mm	Depth of cut, mm	Feed, mm: per rev	Feed, mm: per min	machining	handling

Supersedes inventory No. of original	Inventory No. of original	Date	Signature

Index	Quantity	Revision notice No.	Signature	Date	Index	Quantity	Revision notice No.	Signature	Date

	Signatures	Date	Sheet No.
Drawn up by			____sheets
Rate-setter			
Checked by			
Approved by			
Confirmed by			

Feeds for Drilling Steel (with Grade P18 High-Speed Steel Drills)

Drill diameter, mm	Tensile strength, kg/mm²								
	up to 80			80 to 100			Over 100		
	Feed group								
	I	II	III	I	II	III	I	II	III
	Feed, mm/rev								
Up to 2	0.05-0.06	0.04-0.05	0.03-0.04	0.04-0.05	0.03-0.04	0.02-0.03	0.03-0.04	0.03-0.04	0.02-0.03
4	0.08-0.10	0.06-0.08	0.04-0.05	0.06-0.08	0.04-0.06	0.03-0.04	0.04-0.06	0.04-0.05	0.03-0.04
6	0.14-0.18	0.11-0.13	0.07-0.09	0.10-0,12	0.07-0.09	0.05-0.06	0.08-0.10	0.06-0.08	0.04-0.05
8	0.18-0.22	0.13-0.17	0.09-0.11	0.13-0.15	0.09-0.11	0.06-0.08	0.11-0.13	0.08-0.10	0.05-0.07
10	0.22-0.28	0.16-0.20	0.11-0.13	0.17-0.21	0.13-0.15	0.08-0.11	0.13-0.17	0.10-0.12	0.07-0.09
13	0.25-0,31	0.19-0.23	0.13-0.15	0.19-0.23	0.14-0.18	0.10-0.12	0.15-0.19	0.12-0.14	0.08-0.10
16	0.31-0.37	0.22-0.27	0.15-0.19	0.22-0.28	0.17-0.21	0.12-0.14	0.18-0.22	0.13-0.17	0.09-0.11
20	0.35-0.43	0.26-0.32	0.18-0.22	0.26-0.32	0.20-0.24	0.13-0.17	0.21-0.25	0.15-0.19	0.11-0.13
25	0.39-0.47	0.29-0.35	0.20-0.24	0.29-0.35	0.22-0.26	0.14-0.18	0.23-0.29	0.17-0.21	0.12-0.14
30	0.45-0.55	0.33-0.41	0.22-0.28	0.32-0.40	0.24-0.30	0.16-0.20	0.27-0.33	0.20-0.24	0.13-0.17
over 30 and up to 60	0.6-0.7	0.45-0.55	0.30-0.35	0.40-0.50	0.30-0.35	0.20-0.25	0.30-0.40	0.22-0.30	0.16-0.23

Note: Feed group I — drilling holes in rigid workpieces
Feed group II — drilling holes in workpieces of medium rigidity
Feed group III — drilling precision holes, to be followed by reaming

Axial Force for Drilling Steel (Tensile Strength $\sigma_b = 75$ kg/mm^2, High-Speed Steel Drills, Grade P18)

Drill diameter, mm	Feed, mm/rev											
	0.06	0.08	0.10	0.13	0.17	0.22	0.28	0.36	0.47	0.60	0.78	1.0
	Axial force P, kg											
10.2	99	118	140	168	200	240	285	340	405	485	—	—
12	118	140	168	200	240	285	340	405	485	580	690	—
14.5	140	168	200	240	285	340	405	485	580	690	830	990
17.5	168	200	240	285	340	405	485	580	690	830	990	1,180
21	200	240	285	340	405	485	580	690	830	990	1,180	1,400
25	240	285	340	405	485	580	690	830	990	1,180	1,400	1,680
30	285	340	405	485	580	690	830	990	1,180	1,400	1,680	2,000
35	340	405	485	580	690	830	990	1,180	1,400	1,680	2,000	2,400
42	405	485	580	690	830	990	1,180	1,400	1,680	2,000	2,400	2,850
50	—	—	—	830	990	1,180	1,400	1,680	2,000	2,400	2,850	3,400
60	—	—	—	990	1,180	1,400	1,680	2,000	2,400	2,850	3,400	4,100

Machinability Ratings by Cutting Speeds, Depending on Grade and Mechanical Properties of Steels (Tools Made of Grade P18 High-Speed Steel)

Material machined		Mechanical properties of steel and machinability rating by cutting speeds							
Group of steel	Grade of steel								
Carbon steels Structural steels ($C = 0.6\%$)	08, 10, 15, 20, 25, 30, 35, 40, 45, 55, 60 Cт. 0, Cт. 1, Cт. 2, Cт. 3, Cт. 4, Cт. 5, Cт. 6	Tensile strength σ_b, kg/mm²	30-35	36-41	42-49	50-57	58-68	69-81	82-96
		Bhn	84-99	100-117	117-140	141-163	164-194	195-232	234-274
		K_{mv}	0.86	1.0	1.16	1.34	1.16	$\boxed{1.0}$	0.86
		Machinability rating	7	6	5	4	5	$\boxed{6}$	7
Chromium steels, nickel steels, chromium-nickel steels	15X, 20X, 30X, 35X, 40X 45X, 50X 25H, 30H 20XH, 40XH, 45XH, 50XH 12XH2, 12XH3, 30XH3, 12X2H4 20XH20H4, 20XH3A, 37XH3A	Tensile strength σ_b, kg/mm²	237-43	44-51	52-61	62-72	73-85	86-100	101-119
		Bhn	110-127	128-146	147-174	175-205	206-243	244-285	286-341
		K_{mv}	1.56	1.34	1.16	1.0	0.86	0.75	0.64
		Machinability rating	3	4	5	6	7	8	9

Cutting Speeds for Drilling Carbon and Alloy Steels with Grade P18 High-Speed Steel Drills (Using Cutting Fluid)

Machinability rating of steel	Feed s, mm/rev up to													
1	0.20	0.27	0.36	0.49	0.66	0.88	—	—	—	—	—	—	—	—
2	0.16	0.20	0.27	0.36	0.49	0.66	0.88	—	—	—	—	—	—	—
3	0.13	0.16	0.20	0.27	0.36	0.49	0.66	0.88	—	—	—	—	—	—
4	0.11	0.13	0.16	0.20	0.27	0.36	0.49	0.66	0.88	—	—	—	—	—
5	0.09	0.11	0.13	0.16	0.20	0.27	0.36	$\boxed{0.49}$	0.66	0.88	—	—	—	—
6	—	0.09	0.11	0.13	0.16	0.20	0.27	0.36	0.49	0.66	0.88	—	—	—
7	—	—	0.09	0.11	0.13	0.16	0.20	0.27	0.36	0.49	0.66	0.88	—	—
8	—	—	—	0.09	0.11	0.13	0.16	0.20	0.27	0.36	0.49	0.66	0.88	—
9	—	—	—	—	0.09	0.11	0.13	0.16	0.20	0.27	0.36	0.49	0.66	0.88
10	—	—	—	—	—	0.09	0.11	0.13	0.16	0.20	0.27	0.36	0.49	0.66
11	—	—	—	—	—	—	0.09	0.11	0.13	0.16	0.20	0.27	0.36	0.49

Type of drill point	Drill diameter D, mm, up to	Cutting speed v, m/min													
Double angle with thinned web, *DW*	20	55	55	50	43	37	32	27.5	24	20.5	17.7	15	13	11	9.5
	30	55	55	55	50	43	37	32	$\boxed{27.5}$	24	20.5	17.7	15	13	11
	60	55	55	55	55	50	43	37	32	27.5	24	20.5	17.7	15	13
Conventional, *C*	4.6	43	37	32	27.5	24	20.5	17.7	15	13	11	9.5	8.2	7	6
	9.6	50	43	37	32	27.5	24	20.5	17.7	15	13	11	9.5	8.2	7
	20	55	50	43	37	32	27.5	24	20.5	17.7	15	13	11	9.5	8.2
	30	55	55	50	43	37	32	27.5	24	20.5	17.7	15	13	11	9.5
	60	55	55	55	50	43	37	32	27.5	24	20.5	17.7	15	13	11

Accepted average drill life

Drill diameter D, mm	up to 15	6-10	11-20	21-30	31-40	41-50	51-60
Drill life T, mins	15	25	45	50	70	90	110

Appendix 7

Average Permissible Wear of Cutting Tool Elements

No.	Tool	Material machined and working conditions	Tool material and grade	Dulling criterion (wear)	Tool diameter D, mm	Permissible wear h_3, mm
1	Drills	Steel. With cutting fluid	High-speed steel P18	On lip relief surfaces On margin	$\leqslant 20$	0.4-0.8 1.0-1.2
				On lip clearance surface On margin	> 20	0.8-1.0 1.3-1.5
2		Cast iron. Dry		At outer corners	$\leqslant 20$	0.5-0.8
				of lips	> 20	0.8-1.2
3				On lip relief surfaces at a distance 1.5 mm from corners	—	0.3
4	Core drills	Steel. With cutting fluid	High-speed steel P18	On lip relief surfaces	—	1.2-1.5
5		Cast iron. Dry		At outer corners of lips	—	0.8-1.5

No.	Tool	Material machined and working conditions	Tool material and grade	Dulling criterion (wear)	Tool diameter D, mm	Permissible wear h_3, mm
6	Core drills	Steel and cast iron	Cemented carbide $T_{15}K_6$ BK8	On lip relief surfaces	$\leqslant 20$	1.0
					$\leqslant 40$	1.2
					$\leqslant 60$	1.4
					$\leqslant 80$	1.6
7	Machine reamers	Steel. With cutting fluid Cast iron. Dry	High-speed steel P18	Chamfer relief surfaces	—	0.6-0.8
8		Steel and cast iron	Cemented carbide $T_{15}K_6$ BK8	Chamfer relief surfaces	—	0.4-0.7
9	Machine taps	Steel	High-speed steel P18	Chamfer relief surfaces	—	$0.125d$
10		Cast iron			—	$0.07d$
11	Nut taps	Steel	High-speed steel P18	Chamfer relief surfaces	—	$0.05d$

Diameters of Twist Drills for Various Purposes

(U. S. S. R. State Standard)

Dimensions in mm

Nominal series of diameters	Drill diameters																					
	Drilling through holes									Drilling for subsequent core drilling	Drilling for subsequent reaming or grinding	Drilling for subsequent tapping											
	Precision assembly				Rough Assembly			For aviation rivets	For cotter pins			U.S.S.R. Standard metric thread											
	1st class		2nd class		1st class		2nd class															
	For bolts, screws, studs	For rivets	For bolts, screws, studs	For rivets	For bolts, screws, studs	For rivets	For bolts, screws, studs					coarse pitch	pitch 0.20 mm	pitch 0.25 mm	pitch 0.35 mm	pitch 0.50 mm	pitch 0.75 mm	pitch 1.00 mm	pitch 1.25 mm	pitch 1.50 mm	pitch 2.00 mm	pitch 3.00 mm	pitch 4.00 mm
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0.9	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1	1.2	1.1	1.3	1.2	—	—	—	—	—	—	—	0.75	0.8	—	—	—	—	—	—	—	—	—	—
1.1	—	—	—	—	—	—	—	—	—	—	—	0.85	0.9	—	—	—	—	—	—	—	—	—	—
1.2	1.4	1.3	1.5	1.4	—	—	—	—	—	—	—	0.95	1	—	—	—	—	—	—	—	—	—	—
1.3	—	—	—	—	—	—	—	—	1.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1.4	1.6	1.5	1.7	1.6	—	—	—	—	—	—	—	1.1	1.2	—	—	—	—	—	—	—	—	—	—
1.5	—	—	—	—	—	—	—	—	—	—	1.4	—	—	—	—	—	—	—	—	—	—	—	—
1.6	1.8	—	1.9	—	—	—	—	—	—	—	—	1.25	1.4	—	—	—	—	—	—	—	—	—	—
1.7	1.9	1.8	2	1.9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1.8	—	—	—	—	—	—	—	—	2	—	1.7	1.45	1.6	—	—	—	—	—	—	—	—	—	—
2	2.2	2.1	2.4	2.2	—	2.3	—	—	—	—	—	1.6	—	1.75	—	—	—	—	—	—	—	—	—

[illegible]	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	—	[illegible]	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2.5	[illegible]	—	[illegible]	—	—	—	—	—	—	—	2.4	2.05	—	—	2.15	—	—	—	—	—	—	—	—
2.6	2.8	2.7	3.1	2.8	—	3.1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2.7	—	—	—	—	—	—	—	—	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2.8	—	—	—	—	—	—	—	—	—	—	2.7	—	—	—	—	—	—	—	—	—	—	—	—
3	3.2	3.1	3.5	3.3	—	3.5	—	3.1	—	—	2.9	2.5	—	—	2.65	—	—	—	—	—	—	—	—
3.5	3.7	3.6	4	3.8	—	4	—	—	—	—	3.4	2.9	—	—	3.15	—	—	—	—	—	—	—	—
3.6	—	—	—	—	—	—	—	—	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—
4	4.2	4.1	4.5	4.5	5	4.5	—	4.1	—	—	3.9	3.3	—	—	—	3.5	—	—	—	—	—	—	—
4.5	—	—	—	—	—	—	—	—	—	—	—	3.8	—	—	—	4	—	—	—	—	—	—	—
4.6	—	—	—	—	—	—	—	—	5	—	—	—	—	—	—	—	—	—	—	—	—	—	—
5	5.2	5.1	5.5	5.5	6	5.7	—	5.1	—	—	4.8	4.2	—	—	—	4.5	—	—	—	—	—	—	—
5.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5	—	—	—	—	—	—	—
5.6	—	—	—	—	—	—	—	—	6	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6	6.3	6.2	6.5	6.5	7	6.7	—	6.1	—	—	5.8	5	—	—	—	5.5	5.2	—	—	—	—	—	—
7	7.3	7.2	—	7.5	—	7.7	—	7.1	—	—	6.7	6	—	—	—	6.5	6.2	—	—	—	—	—	—
7.5	—	—	—	—	—	—	—	—	8	—	—	—	—	—	—	—	—	—	—	—	—	—	—
8	8.3	8.2	8.5	8.5	9	8.7	10.5	8.1	—	—	7.7	6.7	—	—	—	7.5	7.2	7	—	—	—	—	—
9	—	—	—	—	—	—	—	—	—	—	8.7	7.7	—	—	—	8.5	8.2	8	—	—	—	—	—
9.5	—	—	—	—	—	—	—	—	10	—	—	—	—	—	—	—	—	—	—	—	—	—	—
10	10.5	10.5	11	10.5	11	10.5	12.5	10.1	—	—	9.7	8.5	—	—	—	9.5	9.2	9	8.7	—	—	—	—
11	—	—	—	—	—	—	—	—	—	—	10.7	9.5	—	—	—	10.5	10.2	10	—	—	—	—	—
11.5	—	12	—	12	—	12	—	—	12	—	—	—	—	—	—	—	—	—	—	—	—	—	—
12	12.5	—	13	—	13	—	14.5	—	—	—	11.7	10.2	—	—	—	11.5	11.2	11	10.7	10.5	—	—	—
13	—	13.5	—	13.5	—	14	—	—	—	—	12.7	—	—	—	—	—	—	—	—	—	—	—	—
14	14.5	—	15	—	15	—	17	—	—	—	13.7	12	—	—	—	13.5	13.2	13	12.7	12.5	—	—	—

Nominal series of diameters	Drill diameters																						
	Drilling through holes									Drilling for subsequent core drilling	Drilling for subsequent reaming or grinding	Drilling for subsequent tapping											
	Precision assembly				Rough Assembly			For aviation rivets	For cotter pins			U.S.S.R. Standard metric thread											
	1st class		2nd class		1st class		2nd class					coarse pitch	pitch 0.20 mm	pitch 0.25 mm	pitch 0.35 mm	pitch 0.50 mm	pitch 0.75 mm	pitch 1.00 mm	pitch 1.25 mm	pitch 1.50 mm	pitch 2.00 mm	pitch 3.00 mm	pitch 4.00 mm
	For bolts, screws, studs	For rivets	For bolts, screws, studs	For rivets	For bolts, screws, studs	For rivets	For bolts, screws, studs																
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
15	—	—	—	—	—	—	—	—	—	—	14.7	—	—	—	—	—	—	14	—	13.5	—	—	—
16	16.5	16.5	17	16.5	17	17	19	—	—	14.25	15.5	14	—	—	—	15.5	15.25	15	—	14.5	—	—	—
17	—	—	—	—	—	—	—	—	—	15.25	16.5	—	—	—	—	—	—	16	—	15.5	—	—	—
18	18.5	—	19	—	20	—	21	—	—	16.25	17.5	15.4	—	—	—	17.5	17.25	17	—	16.5	16	—	—
19	—	20	—	20	—	21	—	—	—	16.5	18.5	—	—	—	—	—	—	—	—	—	—	—	—
20	20.5	21	21	21	22	—	24	—	—	17.5	19.5	17.4	—	—	—	19.5	19.25	19	—	18.5	18	—	—
21	—	—	—	—	—	—	—	—	—	18.5	20.5	—	—	—	—	—	—	—	—	—	—	—	—
22	22.5	23	23	23	24	24	26	—	—	19.5	21.5	19.4	—	—	—	21.5	21.25	21	—	20.5	20	—	—

[illegible]	—	[illegible]	—	[illegible]	—	[illegible]	—	—	—	[illegible]	[illegible]	—	—	—	—	—	—	—	—	—	—	—	—
35	—	—	—	—	—	—	—	—	—	32	34.5	—	—	—	—	—	—	—	—	33.5	—	—	—
36	37	—	38	—	40	—	42	—	—	33	35.5	31.9	—	—	—	—	—	35	—	34.5	34	32.9	—
37	—	38	—	38	—	39	—	—	—	34	36.5	—	—	—	—	—	—	—	—	—	—	—	—
38	—	—	—	—	—	—	—	—	—	35	37.5	—	—	—	—	—	—	—	—	36.5	—	—	—
39	40	—	41	—	43	—	45	—	—	—	—	34.9	—	—	—	—	—	38	—	37.5	37	35.9	—
40	—	—	—	—	—	—	—	—	—	37	39.5	—	—	—	—	—	—	—	—	38.5	38	36.9	—
42	43	—	44	—	46	—	48	—	—	39	41.5	37.4	—	—	—	—	—	41	—	40.5	40	38.9	37.9
44	—	—	—	—	—	—	—	—	—	41	—	—	—	—	—	—	—	—	—	—	—	—	—
45	—	—	—	—	—	—	—	—	—	42	44.5	40.4	—	—	—	—	—	44	—	43.5	43	41.6	40.9
46	—	—	—	—	—	—	—	—	—	43	—	—	—	—	—	—	—	—	—	—	—	—	—
47	—	—	—	—	—	—	—	—	—	—	46.5	—	—	—	—	—	—	—	—	—	—	—	—
48	50	—	50	—	54	—	56	—	—	45	47.5	42.8	—	—	—	—	—	47	—	46.5	46	44.9	43.9
50	—	—	—	—	—	—	—	—	—	47	49.5	—	—	—	—	—	—	—	—	48.5	48	46.9	—
52	54	—	54	—	60	—	62	—	—	49	51.5	46.8	—	—	—	—	—	51	—	50.5	50	48.9	47.9

Notes: 1. The "Precision assembly" column gives the [illegible] instrument manufacture (1st class assembly) and for machinery [illegible].
2. The "Rough assembly" column gives the [illegible] and in other industries.